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THE MUSCLES OF THE EYE

BY

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IN TWO VOLUMES

VOLUME I.

ANATOMY AND PHYSIOLOGY

INCLUDING

INSTRUMENTS FOR TESTING

AND

METHODS OF MEASUREMENT

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PREFACE.

THE importance of this subject becomes apparent when it is remembered that abnormal conditions of the ocular muscles—including those involved in accommodation—constitute, for most ophthalmologists, by far the largest group of cases presented for treatment. Opticians also have to deal constantly with questions in which the ciliary muscle is a factor, and even if they limit their work to giving glasses for presbyopia and hypermetropia, it is desirable that it be done intelligently. All physicians are confronted at times by the numerous reflexes associated with faulty action of the ocular muscles, while their partial or total paralyses are important guides for the neurologists in diagnosis and treatment.

And yet the widely differing views concerning many fundamental facts and principles indicate that thus far we have succeeded only in accumulating a considerable amount of ignorance in regard to this subject. Indeed, there is hardly any branch of medicine about which so much has been written, and of which we know in proportion so little.

It would, therefore, be worse than useless to add to this mass of literature were it not on a plan different in its scope from that of any of the detached articles or text-book chapters on the subject.

The objects of this study are:

First. To collect data relating to this subject, separating as clearly as possible demonstrated facts from statements based on theory.

Second. To formulate these facts concisely, and in the simplest terms possible.

In doing so it is necessary to retain a few mathematical statements, either because they can not be found elsewhere, or to show the basis of other facts. These portions, how-

ever, are made as brief as possible; they are set in small type, and cover altogether about a dozen pages.

The third reason for this study is the desire to supply at least a few of the data which are needed to correlate our anatomical and physiological facts with our clinical experiences.

The book, therefore, is in certain portions a digest of studies in which the writer has been interested for several years. Among the results of these may be mentioned the distinction shown between the primary and secondary insertions, the illustrations of muscular insertions by photographs, a simplified method of recognizing the malposition of the lens with the ophthalmometer, the clinical importance of the accessory muscles of accommodation, another ophthalmotrope, the measurement of the lifting power of the adductors, the clinical measurement by photography of the rate of the lateral movements, the distinction between the actual and apparent static position, between the minimum and maximum dynamic conditions, and the most complete statement yet made of the measurements of relative accommodation, convergence, and torsion.

While this volume is intended as a statement, brief and imperfect though it be, of what we know of this subject at the present time, an attempt is also made to have it useful otherwise to future students, and for this purpose several appendices have been added.

In order to make each volume as complete as possible the questions and references which relate to anatomy and physiology are given in this one, and the remaining parts of these two appendices will follow in the second volume.

Next to the effort to secure exactness and simplicity, the aim of the writer has been to keep constantly in mind the practical aspects of the subject. Whenever any salient point is reached, a halt is called in order to take bearings and determine its relation to the pole-star of clinical experience.

Appreciating fully that passages which appear plain enough to a writer are often confusing to the reader, especially in the treatment of a technical subject like this,

the manuscript, with the exception of the portions in small type, was read by a student who had received hardly more than a high-school education. When he marked a passage as not entirely clear, it was rewritten or stricken out. No future critic can be more unrelenting than he.

Grateful acknowledgment should be made to Professor Kallius of Göttingen for his criticism of the description of the secondary insertions of the muscles, to Professor Bernheimer of Innsbruck for his review of the part relating to the nerve supply, to Professor Hess of Würzburg for his personal demonstration of the action of the lens and for his valuable suggestions concerning relative accommodation, and to Professor Tscherning of Paris for his careful criticism of the first draft of the sections on torsion.

It should be understood that none of these eminent colleagues is in any way responsible for the imperfections of the book, which are so numerous and so evident to the author. But such friendly counsel helps a work greatly in preparing it for the searching criticism with which the reviewer greets a newcomer in the literary field.

Thanks should also be expressed to Dr. Edward Jackson of Denver, who has looked over the arrangement of the whole after it was ready for the press, and to Dr. J. C. Clemesha of Buffalo, who has assisted in the correction of the proofs. In spite of all the attention given to details, it is probable that many faults and omissions will be evident. But such errors will be carefully noted in order that others of a similar kind may not appear in the second volume.

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THE EXTRAOCULAR MUSCLES.

§ 1. **Reason for Reviewing the Anatomy of the Muscles.**—An acquaintance of more than thirty years with ophthalmologists in different countries has convinced me that the study of the anatomy of the ocular muscles is usually sadly neglected. Although an ophthalmic surgeon may have made tenotomies several hundred times, his further knowledge of the muscles is too often acquired from the inspection of a few dissections, or from illustrations in standard text-books. This general neglect of the anatomy is certainly a cause, and with the corresponding neglect of physiology is probably the most important cause of our present ignorance and confusion clinically concerning this subject. Any one who attempts to make dissections of the ocular muscles will find suggestions as to modern appliances and methods very helpful, but on searching he will also realize the paucity of literature on the subject. In view of the improvements in technique which have come into vogue more recently it is worth while to refer to details here which at first may appear suited only to a beginner.

§ 2. **Instruments for Dissection, Preserving Fluids, etc.**—In order to make satisfactory dissections of the orbit it is necessary to have:

1. A back saw, for separating the skullcap.
2. A chisel or chisel-hook.
3. A fine scroll or so-called "jig" saw.
4. Stout, straight bone forceps.
5. Curved bone forceps or ordinary wire nippers.

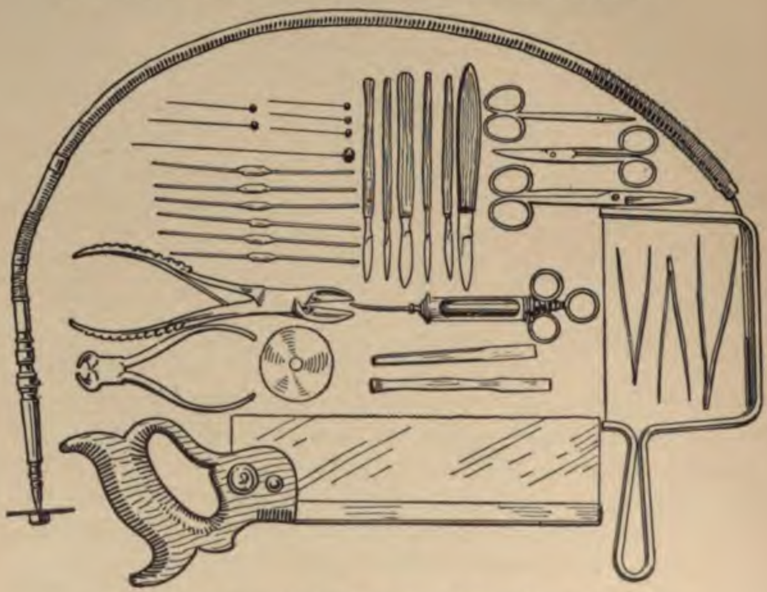

FIG. 1.—Instruments for dissection of the orbit and muscles.

6. A circular saw two or three inches in diameter.
7. A dentist's drill.
8. Half a dozen small blunt probes.
9. A thin spatula.
10. Three pairs of dissecting forceps, large, medium, and very fine.
11. Half a dozen scalpels, large, medium, and small.
12. One elevator or gouge.
13. Two bistouries.
14. Three pairs of scissors, heavy, medium, and small—the last two being finely pointed.

15. A dozen or more steel pins of assorted sizes.

16. Half a dozen small self-closing forceps.

17. A piece of cork, about one centimeter thick and fifteen or twenty centimeters square, upon which the specimen can be fixed during dissection.

18. A small iron vise.

19. An Anel's lacrymal syringe.

The more important of these instruments are seen in Fig. 1.

Preserving Fluids.—It is impossible to complete a good dissection of the orbit before decomposition assails the specimen. In winter this process can be delayed by proper precautions, but preserving fluids are always convenient and sometimes essential. Quite a number of formulas have been proposed for this purpose, but none is entirely satisfactory.

A strong solution of salt water, or a 10-per-cent. solution of carbolic acid in glycerine, will keep the specimen, though the color changes and dissection is rather difficult. The preservative which was most used formerly was a 10-per-cent. solution of chloral hydrate in water; but few, if any, changes of this solution are necessary for preparations of the orbit, but the jar must be large enough to hold a generous supply. More recently, a 4-per-cent. solution of formalin came into vogue and has proved one of the simplest and the best. It has the disadvantage, however, like most others, of rendering the parts hard, and further dissection somewhat difficult.

Kaiserling's method also makes the specimen hard, but not to so great an extent as most of the other mixtures.[1] It has the great advantage, however, when properly employed, of preserving quite well the color of the parts and for that reason deserves special attention.

There are three steps in the process.

First. The specimen is arranged in the desired position and covered with a solution composed of

Formalin	200 c.c.
Water	1000 c.c.
Potassium nitrate	15 grams.
Potassium acetate	30 "

[1] Virchow's *Archives*, 1897, p. 396.

Kaiserling says that the specimen should be left in this from four to six days, but I have found that two or three days are quite sufficient for preparations of the orbital muscles. During this stage it is particularly desirable to keep the specimen in the dark. Indeed, the color of the muscles tends to fade at any time, unless care be taken to protect them from continued exposure to bright light.

Second. The specimen is placed in alcohol to bring back the color of the blood. It has been found that if a dissection be allowed to remain for an hour or so in 80-per-cent. alcohol and then for another hour or more in 95-per-cent. the best results are obtained.

Third. The specimen is then placed in

Water	2000 c.c.
Potassium acetate	200 grams.
Glycerine	400 c.c.

Here it remains permanently, care being taken to protect it from bright light.

A considerable saving can be made, if desired, in the quantity of chemicals used in the solution. If this be filtered and freshened with about a fourth of its bulk of new fluid, the same solution can be used a number of times. Taken all together, this method of Kaiserling's is not only the best thus far proposed for preserving preparations of the ocular muscles when it is desirable to retain the color of the parts, but it is also the one best adapted for the globe, either in a normal or abnormal condition.

Injection Fluids.—We shall see later that to make a good dissection of the orbit it is necessary to distend the globe with air or with some mixture which hardens promptly. One of the best preparations for the latter purpose is

Gelatine	25 grams.
Water	100 c.c.

This can be injected through the optic nerve by means of an Anel's lacrymal syringe.

The space between the optic nerve and the capsule, and

also between the globe and the capsule, can be demonstrated by filling it with some solution similar to that used for injecting arteries. A number of formulas are available for the purpose. One of the simplest is as follows (from Motais):

Purified suet	100 grams.
" oil	10 "
Turpentine	10 "

This is colored with vermilion or Prussian blue, or, better, made with India ink that has already been ground with turpentine.

Hardening or Fixing Fluids.—These are required:

(A) In order to preserve more perfectly the form of the globe and the relation of the parts when the specimen is to be decalcified; and

(B) As the first step in the study of connective tissue fibers (check ligaments) according to methods proposed by Van Giesen, Mallory, and by those which I have used (B 21).

The best solution for this purpose is the one known as *Zenker's Fluid*, which is familiar to all who are accustomed to histological technique. This is composed of

Potassium bichromate	2.5 grams.
Sodium sulphate	1 gram.
Mercuric chloride	5 grams.
Glacial acetic acid	5 c.c.
Water to	100 c.c.

Sublimate Solution.—Another hardening fluid which is useful for several methods of staining consists of a saturated solution of corrosive sublimate. It is well also to add to this .05-per-cent. of glacial acetic acid. Sublimate requires a longer time and does not penetrate the specimen so thoroughly, but it is free from the deep yellow stain of the Zenker fluid.

Alcohol.—A 95-per-cent. solution of alcohol is still occasionally used for preserving and fixing the specimen, if the student desires to study the check ligaments and the connective tissue by means of the stains proposed by Ribbert or by Unna. This, however, does not give the best results,

and alcohol is now largely superseded in the laboratory by other preserving fluids.

Formalin.—The specimen may be hardened in a 4-per-cent. solution of formalin or in the manner proposed by Kaiserling, but this is not adapted to the subsequent staining of the connective tissue.

Decalcification.—It is often necessary in making microscopical sections to have the bony parts of the orbit thoroughly decalcified. The process is an important one and if improperly done the specimen may be injured or ruined entirely. As a preliminary step it is desirable to harden the part in one of the fixing solutions just described. As to the various acid mixtures used for decalcifying, a number of trials indicate that the directions given in most of the books on histology are misleading, when applied to studies of the orbit and to the eye. The difficulty is that these mixtures are too strong.

If the bone around the opening of the orbit be cut down to a thin layer in the first place, and if an abundant supply of the mixture be used, or if it be changed every three or four days, the specimen will be ready for further dissection at the end of two or three weeks. As soon as decalcification is complete the specimen should be removed from the acid (as disintegration continues afterward), and it can then be kept in 60-per-cent. alcohol for further study. A certain amount of softening occurs almost inevitably. It can, however, be reduced to the minimum by enveloping the bony pyramid in absorbent cotton or cloth, and then dropping upon this enough of a 20-per-cent. or even a 30-per-cent. solution of hydrochloric acid to keep the cotton saturated. With care in doing this the decalcification can be completed rapidly and with but little effect on the soft parts.

The formula given by Pereyni is excellent. It is as follows:

4 parts of a 10-per-cent. solution of nitric acid.
3 parts of a 95-per-cent. alcohol.
3 parts of a 0.5-per-cent. solution of chromic acid.

As it contains no corrosive sublimate, however, it is useless for those stains which involve the mercury reaction.

§ 3. **Dissections of the Orbits of Animals.**—These offer an excellent opportunity for practising methods of dissection. It might be taken for granted that doctors of medicine can make, without difficulty, any dissection of the orbit which may be desired, but unfortunately a few attempts usually prove that such is not the case. There are details of technique to be followed which are not always learned in the college dissecting-room, or, even if they have been, are probably forgotten. It is, therefore, much easier for one to learn these methods on the eyes of animals before attempting exact dissections of human orbits. Again, such dissections give an opportunity to become familiar with preserving fluids and with various other details which can be acquired only by laboratory experience.

Finally, the results are interesting in themselves, showing how the same general plan of arrangement of the muscles is followed in the orbits of most of the vertebrates.

§ 4. **Dissection of the Human Orbit.**—Having selected a subject which has but little adipose tissue, the orbits or their contents may be removed by two or three different plans. One of the simplest is

(A) The removal of the orbits with their contents. The details of this are as follows:

First. Take off the calvaria. In doing so, make the incision across the frontal bone, passing within a centimeter of the supraorbital ridge.

Second. Make an incision parallel to the first one and below it, beginning near the middle of the nose, passing backward just beneath the lower margin of the orbit and extending almost to the ear.

Third. Another incision with the saw extends from the extremity of the last one and is perpendicular to it. This detaches the part which includes the orbits with their contents.

Fourth. The orbits are separated from each other by a section in the median line, and each orbit is then cleared of superfluous bone. In doing this it is advisable to hold the specimen firmly in a small vise and trim off fragments of the ethmoid, or parts of the edges of the orbit which are thick,

by means of the nippers and the scroll-saw, leaving only the pyramid with its bony covering.

Fifth. The next step is to open this pyramid. If it be desired to study first the origin of the long muscles, the pyramid can be truncated with the saw fifteen or twenty millimeters from the apex. But usually it is better to remove first the roof of the orbit, then the outer or inner wall, and lastly, to detach the apex with the muscles which arise around the optic foramen. With this in view, it is well to cut first a small window in the roof with the saw. The periosteum here is very loosely attached and it is only necessary to pass a pair of strong forceps between it and the bone, allowing the blades to open. In this way the periosteum can be detached as far forward as the frontal ridge. After that, the roof can be broken off piece by piece with the nippers, care being taken, however, not to interfere with the pulley of the superior oblique.

Sixth. The specimen can now be fastened with pins to a table, or, still better, to a piece of cork on the table, and the student can proceed with the dissection of the muscles or other parts of the orbit.

(B) Removal of the orbital contents with the lids and ligaments and with a ring of bone. This method is easier to describe than to execute. An incision is first made with a scalpel through the soft parts to the bone, about a centimeter from the edge of the orbit and entirely around it. This incision is then deepened by means of the circular saw. Above, it passes first into the frontal sinus, and then, going deeper, it reaches the periosteum. Care should be exercised, at this point, not to injure the levator palpebræ or deeper portions, and it is therefore necessary to feel one's way cautiously with a small blunt probe.

Having reached the periosteum the incision made by the circular saw is extended toward the external canthus, following the curve of the orbital ridge. After the cut has advanced even a short distance, a blunt probe can be readily introduced into the opening, separating the periosteum from the bone. Sometimes it is desirable to pass through the opening a flattened probe, or even a thin spatula, in order

to separate the periosteum from the bone. If neither of these can be passed through the first incision, a second one is made parallel to the first and about half a centimeter above. In this way the incision is extended from one end of the orbital ridge to the other. At its inner extremity, in order to avoid injury to the pulley of the superior oblique, the cut must be almost horizontal. At the outer and inner angles it is necessary to make rather an abrupt turn, the incision passing almost perpendicularly to the one on the supraorbital ridge. At this point the circular saw is rather unsatisfactory, and it is better to use a sharp chisel.

The incision along the lower margin of the orbit can be made in the same way as that along the upper margin. But even after this is accomplished, care and patience are still necessary in order to complete the dissection of the periosteum from the bone, especially in the lower and outer portion, along the line of the sphenoidal sinus. Finally, when the rim of bone is loosened, a pair of thin scissors can be passed into the orbit, then cutting the optic nerve with the muscles, the orbital tissues come away all together. This method is to be selected only when permission can not be obtained to open the skull, but when, in spite of that, it is desired to study quite exactly the check ligaments and the insertions of the muscles.

(C) Removal of the orbital contents with the lids and ligaments, but without the edge of the orbit. This is always easy, although the specimen is, of course, very incomplete. The incision begins at the root of the nose, over the lacrymal sac, and, arching upwards, follows the orbital ridge just below the line of the brow, then, curving downwards, it passes inward along the lower margin of the orbit to the place of beginning. This incision is deepened to the bone. The knife is laid aside and the periosteum lifted off carefully with the elevator. It is slow work over the edges of the orbit, but when once past that the attachments to the bone are slight, except near the deeper portions. The mass can then be separated by a few cuts with the scissors and removed.

(D) Removal of the muscles without their ligaments. It

happens frequently that our dissection must be limited to incisions which leave as little trace as possible. Quite a satisfactory specimen can be obtained by making an incision ten or fifteen millimeters long straight out from the external canthus; then, at the extremity of this incision, another, at right angles to the first and about the same length. Both together, therefore, form a letter T lying on its side. The next step is to evert the lids and dissect out the contents of the orbits. A little patience is necessary in doing this, especially where the tissue is dense near the outer and inner angles of the eye; the cuts should be made carefully, and it is better to snip one's way along with pointed scissors than to advance with a scalpel. When this has been accomplished, the contents of the orbit can be removed as before described.

When we are not permitted to disfigure the face of the subject in any way, it is still possible to remove the greater part of all of the muscles by following this same plan, without first cutting the canthus. The specimen, however, is not very satisfactory and lacks so much as hardly to repay the trouble of exact preparation and dissection.

§ 5. **Inflation of the Globe.**—Immediately after death the cornea becomes flaccid, the globe loses its tonicity, and as the intraocular fluids evaporate it gradually sinks into the orbit. In all specimens which are not perfectly fresh the globe has ceased to retain its normal relation to the muscles and other surrounding tissues. Especially is this a characteristic of cadavers which have been frozen, and as every dissecting-room now has a freezing apparatus, human eyes which are available for study are often thus sunken and contracted. It therefore becomes necessary to restore the globe to its normal form and thus reëstablish the relations of the muscles attached to it.

The most effective method of doing this is to inflate it. The process is simple. The orbital contents having been removed by following any one of the plans already detailed, the student turns the apex of the cone towards him, and with two pairs of forceps carefully picks out the optic nerve. This nerve, with its sheath and with the connective tissue

surrounding it, is dissected out for a half or a third of its length. A long, straight, triangular needle is passed into the center of the nerve, and by twisting the needle on its axis the nerve tissue oozes out from its sheath. On reaching the point where the optic nerve passes into the globe considerable resistance is offered by the lamina cribrosa, but after passing that the globe is easily punctured. The needle is then withdrawn, a blow-pipe is inserted through the canal thus made, and a stout linen thread having been passed around the nerve sheath, the globe is inflated and at the same moment the knot of the thread is tied. With the return of the globe to its normal form, the muscles also resume their normal relations.

§ 6. **Lines of Origin at the Apex of the Orbit.**[1]—In any study of the ocular muscles it is natural to begin with their origins and to examine the point from which most of them spring. For this purpose it is convenient to truncate the cone of an orbit which has been properly preserved in the Kaiserling or some similar fluid, when with a little dissection we can easily see the relation of the parts to each other. When coming now to the names of the muscles it should be observed that it would accord better with modern nomenclature to describe the rectus *medialis* instead of the rectus *internus*. But English-speaking students know that muscle as the *internal*—not as the *median* rectus, and that fact must be accepted until changed by some formal agreement among ophthalmologists as well as anatomists.

Of the six muscles which move the eye, five of these, and also the levator palpebræ, arise from the apex of the orbit. Some confusion exists as to the relative position of these origins, caused to a great extent, as Dwight (B 20) has observed, by the unnecessary complications in different descriptions. These complications are of comparatively recent

[1] In most of the works on descriptive anatomy it is customary to follow each muscle in turn from origin to insertion. For our purpose, however, it is simpler, and from the clinical standpoint it is better, to consider first the common origin of those which come from the apex of the orbit, then each muscle in detail, and, finally, to study the primary and secondary insertions of each, and the relations of all to the fascia or ligaments which connect them to the adjacent tissue or to the margin of the orbit.

date, for one of the earliest anatomists, Zinn, describes the muscles as arising from what he called the ***annulus tendineus communis***. This tendinous "ring," so called, surrounds the optic nerve, and from it the greater number of the muscles spring, each one from the part of the ring corresponding to the portion of the eye into which the muscle is inserted. Fig. 2 shows the lines of origin of these muscles.

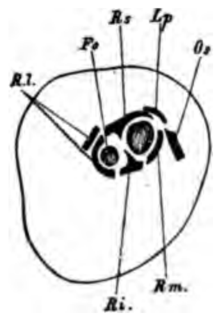

FIG. 2.—Lines of origin of the muscles at the apex of the orbits (Merkel). In this figure and in others which follow, taken from continental anatomists, *R* means rectus, *m*, medialis or internus, *l*, lateralis or externus. Other lettering usually the same as in English and American text-books.

It will be seen that there is not in reality a simple ring around the optic nerve. The lines of the muscular origins, when taken altogether, may be compared rather to the figure eight tipped toward the median line. The inner and upper loop of this figure, being somewhat the larger, surrounds the optic nerve; the lower and outer loop, the one around the foramen, is that through which the motor oculi nerve makes its entrance into the orbit. (Fig. 2.)

The origin of the superior rectus forms the greater part of the upper side of this figure eight, some of the fibers running down between the two openings for the optic and for the motor oculi nerves. The median portions of this loop or circle around the optic foramen are formed by some of the fibers of the internal rectus. The origin of the inferior rectus is situated below these two loops, near their junction.

The external portion of the outer loop is formed by one head of the externus. This muscle, however, has another head, which arises from the outer margin of the superior orbital plate of the sphenoid. In this way the muscles surround the foramina for the entrance of the optic and the motor oculi nerves into the orbit. The levator palpebræ arises from a curved line situated nearer the upper and inner margin of the orbit, the line of origin being almost con-

centric with the optic foramen. The arrangement of the muscles themselves at the apex of the orbit is seen in Fig. 3.

§ 7. **Meaning of the "Primary" and "Secondary" Insertions, and Other Preliminary Considerations.**—Having thus glanced at the origins of the extraocular muscles which arise at the apex of the orbit, we are ready to consider each one in turn. But when doing so, as we pass to the attachment of each into the globe, mention must be made of the "*Primary*" and "*Secondary*" insertions. As those terms will be new to most readers, it is desirable here to give an idea of what is meant, although they will be considered more in detail later.

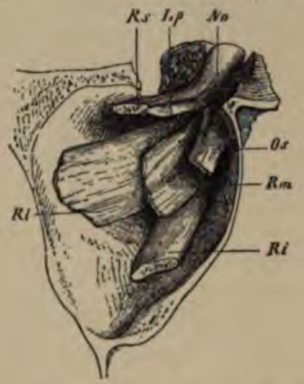

FIG. 3.—Apex of the orbit with muscles in position. *Rs*, rectus superior; *Lp*, levator palpebræ; *Os*, obliquus superior; *Rl*, rectus externus; *Ri*, rectus inferior; *Rm*, rectus internus; *No*, nervus opticus (Merkel and Kallius).

It happens frequently throughout the body that the insertion of a muscle is strengthened by lateral extensions more or less complete, or by two or more distinct points of attachment. Ordinarily these supplementary insertions are of no special importance physiologically or clinically. With the ocular muscles, however, we shall see that even small fibers of connective tissue, so small as to be seen with difficulty, and not situated directly in the line of insertion, may affect the position of the globe to an important degree. With our increasing knowledge of these accessory fibers it becomes clear that we should study them as carefully as we study those other fibers, which, being joined together, form the tendon going to the main insertion. We must therefore take into account not simply the *primary* or *principal insertion*, but also these accessory insertions of the muscles which may properly be called *secondary*.

It may seem an unnecessary refinement to give as much attention to details as will be found presently in the

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measurement of these secondary insertions or in the exact size of the different muscles. But second thought shows the value of such care. Thus, it has occurred to every operator, while doing a tenotomy, to find that a division of the merest thread of connective tissue will make a very decided difference in the result, and if we know what to expect in the average case as to the position and length of the line of insertion it is an evident assistance. Or if, after making the division of the tendon, the surgeon finds that the line of insertion is placed obliquely to its ordinary position, and that he has to do with an extreme variation, he infers that other muscles must also be inserted in unusual positions in order to produce a proper compensating effect. In other words, such a case will probably require subsequently more than ordinary care either by some of the non-operative methods of treatment, or possibly by further operations. In a similar manner the number of square millimeters exposed when a muscle is divided transversely should also be taken into account. This means, of course, the contracting power of one as compared with that of its antagonist. When we come, later, to consider the different reasons which have been given by Graefe, by Hansen Grut, and others to account for the various forms of apparent deviations, it will be seen that the relative strength of different muscles or groups of muscles is no small factor in deciding these important questions of etiology. Or, again, as to these details of the primary or secondary insertions, it is probable that the disregard of such points is one of the main reasons of our confusion and ignorance concerning certain aspects of this part of ophthalmology.

When considering the extraocular muscles it is necessary to bear in mind a peculiarity in their structure to which attention has been called recently by Schiefferdecker (B 24). It has long been known that in various portions of the body elastic connective tissue fibers are found both in the epimysium and also in the perimysium. A careful examination by this observer, however, shows that such elastic fibers are much more abundant in the ocular muscles than elsewhere, this being especially noticeable in the superior rectus. The

general direction of these elastic fibers is usually the same as that of the muscle, but they also intertwine with each other, often forming a network of anastomoses. It is probable that the abundance of these fibers in the ocular muscles assists materially in the rapid and frequent motions of the globe.

§ 8. **The Levator Palpebræ.**—After the pyramidal contents of the orbit have been removed by following one of

FIG. 4.—View of the upper surface of the orbit, showing the levator palpebræ with the insertions which pass outward and inward (Merkel and Kallius).

the plans already described, if we dissect off the periosteum which lines the roof of the orbit, we find a muscle lying just beneath, which passes from the apex of the pyramid almost straight forward. This is the levator palpebræ.

It arises from a small head two or three millimeters above the optic foramen, just beneath the periosteum which lines the roof of the orbit, and then, passing forward, spreads out into a broad tendon. But all of the fibers do not pass directly to the cartilage of the lid. Those near the outer edge branch off toward the lacrymal gland, forming a firm

network supporting it (Figs. 4 and 5), and those near the inner edge bend around almost at right angles toward the pulley of the superior oblique. In reality, therefore, the levator palpebræ has not a single insertion into the edge of the superior cartilage, but in a certain sense it may be said to have three insertions, a central, external, and internal.

Let us examine more exactly this central portion of

FIG. 5.—Levator palpebræ, inferior surface.

the fibers of the levator. The earlier anatomies and some of the general text-books still describe the tendon of the levator as passing forward to be inserted into the upper border of the cartilage. More careful study, however, showed that this was not quite true. The fact is that as the tendon of the muscle approaches the cartilage it divides into at least two layers. The lower one of these passes directly to be inserted, as already described, into the upper

edge of the cartilage. This small band of fibers, having been described first by Müller, is called after him. The upper layer of the tendon passes over the upper edge of the cartilage, and is inserted into its upper and anterior surface, where the fibers blend with the fibers of the orbicularis. These two divisions of the muscle are well defined and are figured by Schwalbe (B 13) as quite distinct.

Recently another description of the insertion has been given by Wolff (B 25). He has shown that the anterior or upper layer of muscular fibers continues over the whole anterior surface of the cartilage, extending almost or quite down to its lower border.

The method of insertion of the tendon of the levator is of evident importance in all of those operations for ptosis which involve in any way the insertion of the muscle,—such, for example, as the operations of Motais, Hotz, Wolff, the success of each one of these procedures depending upon a knowledge of the anatomical relation of the cartilage to the muscle.

The action of the levator is really to lift the lid. But as the path of the muscle from its origin to the lid is not directly forward, but also outward, its natural tendency would be to draw the lid up and inward. That, however, is counteracted by the two lateral groups of fibers.

§ 9. **The Internal Rectus (Rectus Medialis).**—As the internal is one of the most important, clinically, of the recti, we will consider it first. It arises from the inner and lower border of the ligament of Zinn, having its upper edge in contact with the origin of the levator palpebræ and the superior rectus. Its lower margin is in contact at first with the origin of the inferior rectus, while still farther to the inner side, and lying close to the wall of the orbit, is the origin of the superior oblique. The internal is smaller near its origin than the external rectus, but soon expands into a fleshy belly. As it passes forward it is in close contact with the internal wall of the orbit, having its upper edge at first almost continuous with the superior oblique. But as the muscles advance, the internal rectus continues horizontally forward toward its insertion into the sclerotic, while

2

the superior oblique is directed toward the pulley at the upper and inner margin of the orbit. The relations of the muscles in the orbit can be seen best in frozen transverse sections. These are very easily made, especially in winter, the following drawings of such sections being taken from

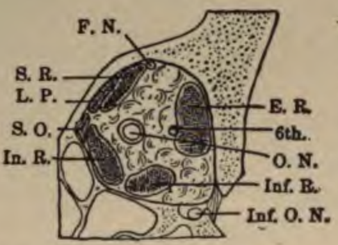

FIG. 6.—Frontal section of frozen right orbit, about twelve millimeters behind globe. Seen from behind. S. R., superior rectus; L. P., levator palpebræ; S. O., superior oblique; In. R., internal rectus; Inf. R., inferior rectus; E. R., external rectus; O. N., optic nerve; F. N., frontal nerve; Inf. O. N., infraorbital nerve; 6th, sixth nerve.

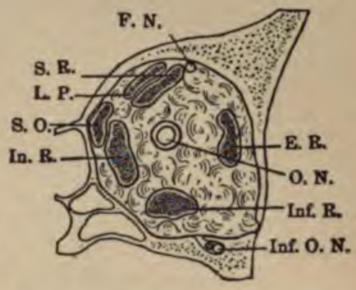

FIG. 7.—Section about five millimeters behind globe. Letters as in preceding figure.

Dwight (B 20). The relations of the internal rectus vary somewhat. Thus, near its origin, it lies rather to the lower and to the inner side of the orbit; above it and to the inner side is the superior oblique, and above and externally is the optic nerve, from which it is separated by a cushion of fat. Below and internally is the wall of the orbit, with which it lies in contact. When the muscle has advanced, however, to within five or six millimeters behind the eye, its relation is somewhat altered, having assumed a relatively higher position. Farther forward, the relations of the internal rectus are modified still more. Then the superior oblique lies almost above it, the center of the muscle being quite on a line with the center of the globe. See Figs. 6, 7, 8, 9.

The principal insertion[1] of the internal rectus is in a line slightly convex to the margin of the cornea or almost parallel to a line tangent to it. The center of the insertion

[1] Figures 10, 11, 12, 13, 14, 15, 16, 27, and 28 are from my dissections and the photographs are purposely left untouched.

is on the average five or five and a half millimeters from the cornea, near the point where the globe is intersected by the horizontal plane passing through its center. In a few instances the center of this insertion is one or two millimeters below that point—very rarely above it. Also, the line of insertion may be inclined so that its upper end is nearer to the cornea than the lower, or the reverse. Such variations from the type are less frequent with the recti than with the oblique. The secondary insertions of the internal rectus are always present and naturally are of importance clinically. From each edge of the tendon, above and below, fibers of connective tissue spread off toward the sclerotic, so that sometimes when the muscle is drawn out at right angles to the globe it is difficult to determine at exactly what point the tendon proper or the primary insertion ends, and just where the lateral connective tissue fibers, or secondary insertions, begin (Fig. 11). On certain globes, however, these secondary extensions above and below are exceedingly small and thin.

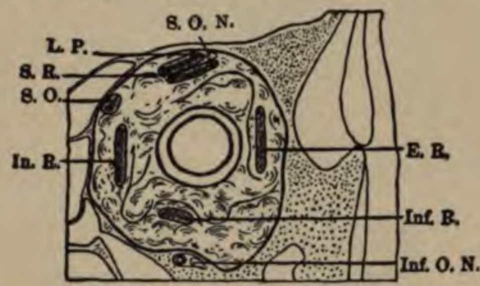

FIG. 8.—Section about three millimeters in front of entrance of nerve. Letters as before. S. O. N., supraorbital nerve.

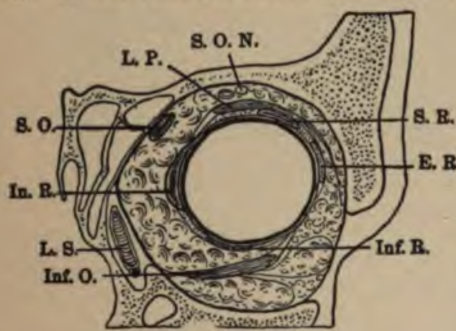

FIG. 9.—Section near equator of globe. Letters as before. Inf. O., inferior oblique; L. S., lacrymal sac.

Secondary attachments connecting the ocular surface of

the internal rectus to the globe are always present. These fibers, usually very minute, are situated near the primary insertion, passing from the sheath of the muscles to the outer part of the capsule of Tenon, and, it is needless to say, play a very important part in every operation of tenotomy of this muscle.

Secondary attachments on the median or orbital side of the internal rectus are also important. They, too, are always present, though their firmness and abundance vary in dif-

FIG. 10.—Internal rectus, median surface; the superior oblique lies just to its left. The superior rectus is in profile to the extreme left.

ferent subjects. By staining horizontal sections properly, these fibers from the sheath of the muscle can be easily seen beginning several millimeters posterior to the principal insertion. The more posterior fibers pass almost directly forward, those more anteriorly pass both forward and inward, and, interlacing with other fibers, blend with the central portion of the fascia orbito-ocularis. In this position they form a portion of what is called the internal check ligament. According to Schneller the rectus internus has the following dimensions: length, 40.7 mm.; width, 10.3 mm.;

FIG. 11.—Internal rectus, ocular surface, with the ocular secondary insertions.

FIG. 12.—Internal rectus; superior lateral edge is held in the forceps.

thickness, 1.6 mm. In section it measures 17.4 square mm. Its volume is 709. cbmm. Its weight is 0.747 grams. (B 24.)

§ 10. **The External Rectus (Rectus Lateralis).**—Unlike the other ocular muscles this has, as already mentioned, two points of origin, one from the outer margin of the optic foramen, and the other from the ligament of Zinn and its extension. A small opening is left between the two heads, and through this pass the third and sixth nerves, and the nasal branch of the fifth together with the ophthalmic vein. The two heads of this muscle join almost immediately, and in the posterior portion of the orbit form the outer segment of the cone of muscles surrounding the optic foramen. In the deeper portions of the orbit the external is seen on section to be the largest of the group (Fig. 6). As it passes forward towards the upper and outer portion of the globe, its transverse section presents an ellipse, the longer diameter being from above downward. On the inner side it is in contact with the orbital fat, and on the outer side with the bone.

When a transverse section is made of the orbit, 5 or 6 millimeters from the globe (Fig. 7), we find that the relations of the external rectus have changed somewhat. It is now smaller than near its origin, more circular in shape, and is surrounded on all sides by fat, being at this point about on a line with the optic nerve.

The sixth nerve passes along the inner surface of this muscle, which it supplies, and posteriorly the ophthalmic artery lies close to its upper and inner portion; farther forward the lacrymal artery often courses along its upper edge, and anteriorly, near its insertion, it is in relation above with the lacrymal gland.

The principal insertion is in form, position, and size nearly the counterpart of the opposing muscle—the internal rectus. The insertion of the external is convex toward the cornea, the center of the line being near the horizontal plane of the eye. The external rectus is, however, inserted farther back than the internal, the center being on the average not far from 7 mm. from the corneal edge.

Occasionally one end of this line is farther from the edge

of the cornea than the other end, the variations being about equal. The secondary insertions of the external rectus follow the same general plan as those of the internal. At each edge of the tendon, above and below, we usually find filaments of connective tissue. These are also seen connecting the ocular surface of the muscle near its insertion with the capsule of Tenon, and from the external flat surface of the insertion fibers of connective tissue bend upward, and especially outward, to blend with other fibers, forming part of the fascia orbito-ocularis or external check ligament.

FIG. 13.—External rectus. External surface. The fascia orbito-ocularis is seen by reflected light with a fold of connective tissue passing from the external surface of the muscle to the margin of the orbit.

The following measurements have been made of this muscle by Schneller: length, 45.8 mm.; breadth, 9.2 mm.; thickness, 1.6 mm.

The relation between the thickness of the internal rectus muscle and that of the external has been studied accurately, and exact measurements of this relation have been made by Fuchs, Volkmann, and Schneller.

The plan adopted was to make transverse sections of these muscles through their fleshy portions and measure the number of square millimeters of surface thus presented by the divided ends. As a result Schneller found that the internal rectus measured 39 square millimeters, while the external rectus measured 26, giving a relation between the two of about 100 to 66.6. Thus, although the fleshy part of the externus is broader from above downward than the

internus, the latter muscle, being thicker in a horizontal direction, contains a larger number of square millimeters in section. The weight of the two muscles is about the same, according to Adachi, being for the internal rectus 0.57 gram and for the external 0.56 gram.

It is interesting also to observe to what degree the lateral recti are shortened when the eye turns in or out. This has been estimated with considerable exactness by Schneller. (B 19.) When the eye makes an excessive rotation, turning inward 45 degrees there is a shortening of the internal rectus of about 23.5 per cent. of its length, but when it turns outward 40 degrees from the contraction of the rectus externus, there is a shortening of about 16.75 per cent.

§ 11. **The Superior Rectus** arises along the upper edge of the two openings or figure of eight from which the other muscles spring. The curve of its origin has its concavity downwards, some of the filaments commencing also from the division between these two foramina. The muscle is somewhat ribbon-shaped, except near its origin, where it is more rounded. A cross-section of the orbit near the apex (Fig. 7) shows this muscle, thin and flattened, lying at the upper and inner portion, touching internally the levator palpebræ, and having its upper edge only in contact with the roof of the orbit. More anteriorly we find that its position has changed somewhat. The long diameter is now more nearly horizontal (Fig. 8). It is in contact, by its inner and upper surface, with the levator palpebræ; below and inward it rests upon the fat, while its external edge is in contact with the frontal nerve. Still farther forward the long diameter of its section is almost horizontal, and the levator now rests upon and covers the superior rectus. The superior orbital nerve lies upon this muscle near its outer edge, and usually also the ophthalmic artery and vein and the ophthalmic branch of the fifth nerve.

The principal insertion of the superior rectus is in the form of an arc, somewhat convex anteriorly, the center of the line being rather to the inner side of the vertical meridian of

the eye. It is usually 7 to 8 mm. from the edge of the cornea. The length of the line of insertion is on the average not far from 10.5 mm., its inner end being decidedly nearer the cornea than the outer. The secondary insertions are well marked (Fig. 14). There are, as usual, not only the fibers at each edge of the tendons, but also fibers passing from the ocular surface near its insertion to the capsule of Tenon, and other fibers passing from the upper flat surface to the adjacent tissue. These fibers are especially

FIG. 14.—Ocular surface of superior rectus and levator.

abundant near the outer edge of the tendon, where they blend with the network that holds the lacrymal gland in place.

The following measurements have been made of the muscle: length, 41.8 mm.; width, 9.2 mm.; thickness, 1.6 mm.; in section, 11.3 square mm.; weight, 0.51 gram.

The structure of the superior rectus is of interest because, as already observed, it contains in its epimysium and also in its perimysium a greater abundance of elastic connective

tissue fibers than is found in any other part of the body, or even in any of the other ocular muscles. (B 25.)

§ 12. **The Inferior Rectus** arises from the space between the optic foramen and the opening for the motor oculi. At first the muscle is round, but almost at once it flattens, so that its section forms an ellipse (Figs. 8 and 9), and lies in the lower part of the orbit, somewhat external to the optic nerve. Above and to the outer side it is covered by fat, and internally it is almost in contact with the internal rectus.

When seen farther forward it is more nearly below the optic nerve and is entirely surrounded by fat; farther forward still, the relations are practically the same, though, as it approaches the globe, it flattens out yet more, the long diameter being horizontal as it passes towards its insertion.

The primary insertion of the inferior rectus is in a line always convex to the margin of the cornea. The center of this curve is usually near the vertical plane of the globe, though, in occasional instances, the center of the insertion lies a little to the outer side of that point.

The average distance of the center of the primary insertion from the cornea is about 5.5 mm., and its length is from 9.8 to 10.3 mm., the inner end of the line being almost invariably nearer to the cornea than the outer.

The secondary insertions of the inferior rectus are interesting and sometimes important, clinically. At each edge of the tendon there are the usual small bands of connective tissue, more or less marked, and the ocular face of the tendon is also connected, near its insertions, with the outer surface of the capsule of Tenon. Very important secondary attachments also bind the sheath of the inferior rectus to that of the inferior oblique, as can be seen after using selective stains for connective tissue. The abundance and general direction of these fibers are imperfectly shown in

FIG. 15.—Vertical section of inferior oblique and inferior rectus, showing secondary connective tissue attachments to the inferior oblique.

the accompanying illustration of a vertical section (Fig. 15). Other fibers from the lower surface of the muscle pass laterally and forward to blend with fibers from the inferior oblique, all of which, curving around the eyeball, have been called, as we shall see later, 'the suspensory ligament.' The measurements of the inferior rectus given by Volkmann are as follows: length, 40 mm.; in section, 15.85 square mm.; weight, 0.67 gram.

§ 13. **The Superior Oblique** comes from the apex of the orbit, at the upper and inner side of the ring of muscular fibers which surround the optic foramen. Indeed, the fibers of this muscle, at its origin, lie so close to the superior and internal recti that there is usually some difficulty in separating them. Near its origin it is noticeably smaller than the superior and internal rectus. As it passes forward it increases in size, being somewhat fusiform, but as it approaches the pulley it gradually decreases in bulk, at the same time becoming tendinous, and when it reaches that point it is hardly more than three or four millimeters in diameter. After passing through the pulley it is reflected outward and backward, to be inserted into the sclerotic, near the upper portion of the upper and outer quadrant of the posterior half of the globe.

Between the pulley and the point of insertion the character of the muscle is entirely changed. It no longer looks like a muscle, but is tendinous in character, and as the fibers spread out, fine and glistening, they resemble rather an aponeurotic covering of the globe. Or, let us consider its course more in detail.

When we examine a frontal section of the orbit, made near its apex, the superior oblique is not found in the upper and inner corner, as we might expect, but about on a level with the optic nerve, at the extreme inner edge of the orbit. (Fig. 6.) In this position it lies close to the bone. Above it are the superior rectus and the levator, while below and externally to it, is the inferior rectus. When a transverse section, made a little farther in front of this, is examined, the appearance differs but slightly from the last. The muscle in section is larger than before, triangular in form,

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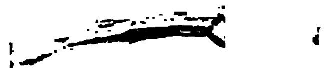

FIG. 15.—Vertical section of in. ferior oblique and inferior recti showing secondary connective tiss attachments to the inferior oblique

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terior half, so that the curve is convex posteriorly. In some cases nearly half of the line is on the median side of the vertical meridian. The other type of the line of insertion is quite different. In this, the end of the line which is nearest to the cornea begins in the upper and outer quadrant of the posterior half of the globe two or three millimeters behind the equator; the line then runs almost straight backward at

FIG. 16.—Tendon of the superior obiique, showing its primary insertion and the lateral secondary insertions. The one on the left side is particularly well marked.

an angle of about forty-five degrees with the vertical plane, and within three or four millimeters of the point where that plane would cut the globe. This line of insertion is either straight, or, as already stated, slightly convex. Between the two types there are great variations in detail, not only as to the length of the line and the degree of its convexity, but also as to the angle which the central fibers of this

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Nor is the position always the same. Its posterior end usually begins 2 or 3 mm. from the optic nerve, but this varies greatly, being dependent somewhat on the length of the eye.

This muscle, like the others, is covered with comparatively little connective tissue near its origin, but, as it advances, the fibrous covering increases in thickness and gives off small attachments to adjacent structures. Beneath the inferior rectus numerous fibers are given off posteriorly and superiorly, connecting the sheaths of the two muscles. Near this point also, other fibers are directed anteriorly to form part of the fascia orbito-ocularis, and especially the suspensory ligament of Lockwood. As the muscle then advances to its principal insertion, it gives off fibers to the globe and also a few which go to the connective tissue of the orbit, though these are usually small and sometimes absent. Finally, there are, at each edge of the primary insertion, the usual accessory fibers which cause this insertion to merge, apparently by imperceptible gradations, into the adjacent connective tissue.

§ 15. **Measurements of the Primary Insertions and Methods of Recording the Results Obtained.**—As there will be occasion to refer frequently to the exact position of the muscles, it is desirable to know how the landmarks of the globe can be most conveniently located, and measurements made from them recorded accurately for comparison. After an eye has been removed and inflated or injected, it is turned so that when placed on the table it lies in the same position, relatively, that it occupied in the head. This is not always easy, especially for the novice, but a little practice and observation of the lines of insertion will enable one to become quite expert. Another difficulty in measuring the insertions is to obtain fixed lines from which to begin. The edge of the cornea, it is true, serves that purpose fairly well, although not exactly, as the clear portion merges gradually into the opaque. But for measurements of the recti, and especially of the oblique, it is desirable to determine their position with reference to the equator, and to the vertical and horizontal planes. This apparently small

matter is nevertheless one of importance, and as no mention of the point could be found in the literature, and marking the globe with pen or pencil could not be done at all satisfactorily, a simple method was devised which serves the purpose perfectly.

This consists in slipping over the globe, thread-like bands of india-rubber to mark the equator and the vertical and horizontal planes. From these lines measurements can be made with a readiness and an exactness which are eminently satisfactory.

In recording the attachments of the ocular muscles it is convenient to represent the curves of the insertion in the

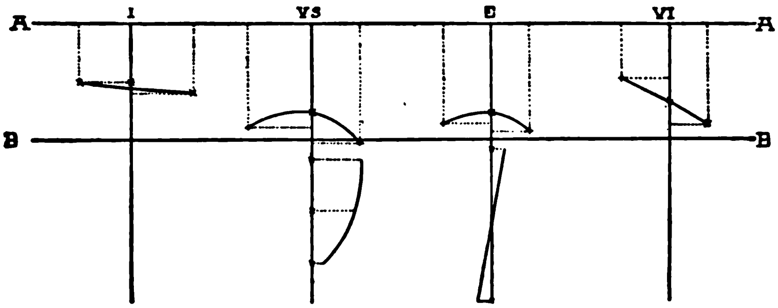

FIG. 18.—Lines of insertion of one eye plotted to a scale. A A, line of the cornea. B B, line of the equator. I, line where a horizontal plane cuts the inner portion of the globe. E, line where a horizontal plane cuts the external portion of the globe. VS, line where a vertical plane cuts the superior portion of the globe. VI, line where a vertical plane cuts the inferior portion of the globe.

same manner as lines on the earth are shown in the ordinary Mercator's projection, and to do this, as Fuchs has shown, on a scale at least four times the size of the globe itself. If, therefore, the diameter of the normal eye is 23 millimeters, the length of the equator is 72.2, and the line on which it is plotted is 288.8 millimeters. In Fig. 18 A A is the line representing the edge of the cornea, and parallel to it is the equator B B. It is true that the cornea is not perfectly circular, but its representation by a straight line is sufficiently exact for this purpose.

Finally, the four perpendiculars are the representations, by the Mercator projection, of the lines in which the globe is cut by the horizontal and vertical planes. From these various lines it is possible to locate the position of the various muscular insertions. If the separate plottings of different eyes be drawn successively on the same paper, we have at a glance the variations which they present.

§ 16. **The Primary Insertions Considered as a Whole.**—In order to ascertain the direction of each muscle, and therefore its line of traction, it is desirable to study each one separately, as we have done. But if we would make comparisons of the insertions we must, of course, consider them together. The results of measurements already quoted are therefore given below, and to these a few other data can be added (B 24). From these it appears that the average distance of the line of insertion of the recti from the edge of the cornea as found by different observers is as follows:

	Fuchs.	Weiss.	Adachi.	Howe.
Internal rectus.........	5.5	5.85	5.5	5.7
Inferior rectus.........	6.5	6.85	6.8	6.7
External rectus........	6.9	6.75	7.3	7.4
Superior rectus.........	7.7	8.01	8.3	7.6

These measurements vary somewhat according to whether the eye be normal or shortened (H) or lengthened (M). It should be observed, however, that in emmetropia the insertions are in the line of a spiral. (Fig. 20.) Commencing with the internal rectus, which is nearest to the cornea, this line curves down, out, and up to the inser-

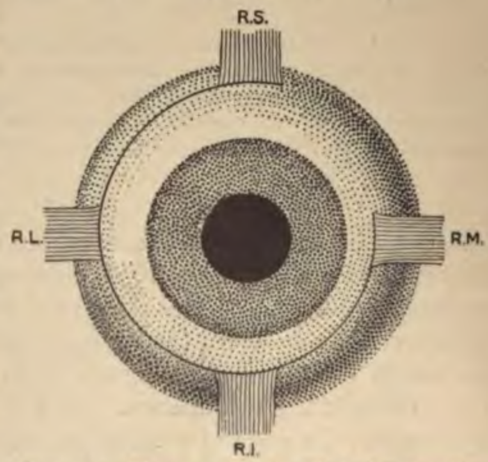

FIG. 20.—Diagram showing that the insertions are approximately in the line of a spiral.

tion of the superior rectus, which is seven and a half or eight millimeters distant from it.

Again, the length of these lines (the breadth of the tendon) is given as follows:

	FUCHS.	WEISS.	ADACHI.
Internal rectus..............	10.3	10.76	9.9
Inferior rectus..............	9.8	10.35	9.0
External rectus..............	9.2	9.67	8.4
Superior rectus..............	10.6	10.75	10.0

It may be of interest to glance at the variations in the position, length, and form of the lines of primary insertions

FIG. 21.—Lines of insertion of several eyes plotted together in order to show the differences in the form and place of the insertion. In this figure all of the right eyes are grouped together in the upper portion, and the left eyes in the lower portion. In both C represents the line of the cornea, E the equator of the globe.

which have been found to exist in a series of twenty-one eyes. Instead of drawing each of these sets of lines on a separate set of meridians, they are all placed upon a single sheet, thus making comparisons possible at a glance. (Fig. 21.)

This plan represents, as has been said, the projection of the globe on a plane surface, like the Mercator map. "Int" is the line in which a horizontal plane would cut the globe on its inner side, and crossing this, of course, are the in-

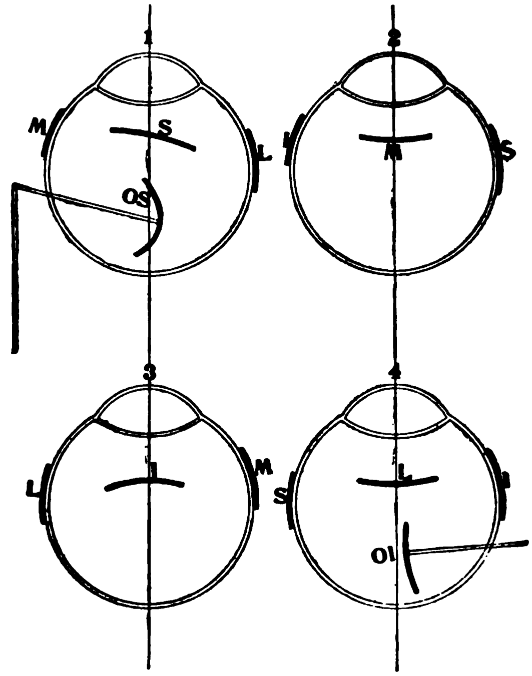

FIG. 22.—The lines of insertion of all the muscles in the **average eye.** Modified by additional measurements from the figure of Merkel and Kallius. M, internal rectus (medialis). L, external rectus (lateralis). S, superior rectus. I, inferior rectus. OS, superior oblique. OI, inferior oblique. No. 1 shows the right eye seen from above, No. 2 seen from the median plane, No. 3 from below, No. 4 from the outer side.

sertions of the different internal recti. "Ex" shows the line in which a horizontal plane would cut the globe on the outer side, and crossing this are the insertions of the different external recti, etc.

While it is evident that very decided variations occur in different individuals in the insertion of some of the muscles, especially of the oblique, an examination of the measure-

ments shows that the insertions of the recti, especially of the internus, are remarkably regular. By taking the average of the measurements in a considerable number of eyes we are able to represent graphically the position which the different muscles assume when we regard the globe from four different points of view—namely, from above, from the median side, from below, and from the temporal side. These are seen in the accompanying Fig. 22, Nos. 1, 2, 3, 4. Schneller has shown (*Arch. f. Ophth.*, 1890, 3, s. 160) that it is possible to measure the position of the line of insertion of the internus or of the other recti while making several of the ordinary operations. He goes so far as to say that in tenotomy with displacement backwards (Rücklagerung) we may lay bare the conjunctival surface of the tendon for six, eight, or even ten mm. with no detriment to the patient; or, when advancement is to be made, for a distance of 10–13 mm.—that is, from a fifth to a quarter of the entire length of the internus.

Although we will have occasion later to question the advisability of such precedures, undoubtedly it would be better if surgeons would take more pains thus to observe the position, direction, and extent of the line of insertion of the tendons of the recti when they are divided, for in many cases the difficulties for which we operate are undoubtedly dependent on abnormal insertions.

§ 17. **The Secondary Insertions.**—In studying these dissections we have already learned not only what the secondary insertions are, but their general arrangement. It remains, however, to classify them more definitely for future reference. As these fibers stretch out in all directions from the muscles near their insertions they may be conveniently divided into four groups. The first forms a continuation of one edge of the tendon, being the *lateral secondary* insertion. For example, in the case of the internal rectus, we have the superior lateral secondary, or in the case of the superior rectus, the external lateral secondary insertion, etc.

A part of this group includes those attachments at the other edge of the tendon; with the internal rectus, we have

the inferior lateral secondary, or with the superior rectus, we have the internal lateral secondary insertion.

These two groups are evidently similar to each other, being simply on opposite edges of the main tendon. They are easily seen by drawing out the muscle at right angles

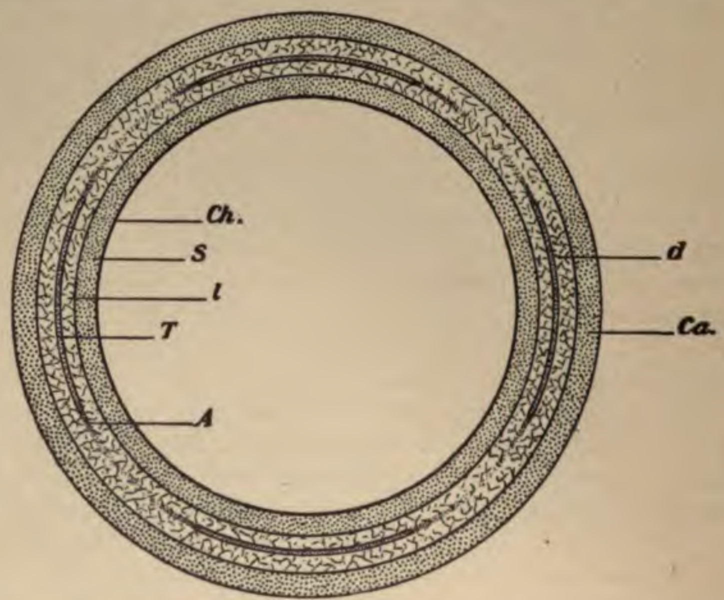

FIG. 19.—Transverse (frontal) section anterior to the equator magnified three times (Hans Virchow). This illustration is especially interesting, as it gives a sectional view not only of the tendons (T) at this point, but also of the connective tissue fibers (A) extending from one tendon toward the next. These are the lateral secondary insertions seen in section. Merkel calls these fibers the *adminiculum tendinis*. At the point where this section is made, the capsule of Tenon (Ca) lies entirely external to the tendons. The clinical importance of the arrangement of the secondary insertions at this point is clear, especially their relation to the various forms of tenotomy and of advancement.

to the globe. These lateral attachments are mentioned first because they are so easily seen and because their clinical importance is so evident.

A second set of fibers constitute what may be termed the *ocular secondary* insertions. These pass from the ocular

surface of the muscle either to the capsule of Tenon, or directly to the sclerotic. If care has been taken not to break these small fibers, they can be seen extending quite far back toward the equator. They appear as minute white fibers stretching from the muscle to the capsule, but occasionally assuming an oblique direction.

These secondary insertions are quite easily seen in transverse and vertical sections of the globe, though it is very difficult to complete the cutting and mounting without disturbing the relation of the muscle and connective tissue fibers.

Finally, there is a third group of fibers which pass from the muscle near its insertion outward in the direction of the orbit and are therefore the *orbital secondary* insertions. These are easy to demonstrate, and they can be seen best, perhaps, when dissecting the anterior portion of the muscle from behind, as described on page 7. If the globe be drawn backward, these fibers can be easily seen stretching from the muscles off in the direction of the margin of the orbit. It is not always possible to follow individual fibers directly from the muscle to the bone, for they blend with other portions of the fascia orbito-ocularis, forming internally and externally a part of that tissue which we shall study presently as the check ligaments.

When examined in thin horizontal sections, these secondary orbital insertions appear to pass in general forward and outward. Those fibers which arise at some distance posteriorly to the principal insertion are for the most part directed somewhat forward; those nearer to the insertion, forward and outward, while the foremost fibers pass outward and even backward.

The arrangement of the secondary insertions of the obliques is in general similar to that of the recti. The lateral secondary insertions are particularly well marked, and as the tendon of the superior oblique, for example, is lifted away from the globe it is usually quite impossible to determine any one point on either side which separates the primary insertion from those lateral expansions of connective tissue which constitute the secondary insertions. We

see simply a broad, glistening band which, being attached to the globe in its central portion, gradually thins out into the connective tissue of the capsule of Tenon on either side. (See Fig. 16.) The ocular secondary attachments are also well marked, being similar to those which connect the recti to the outer portion of the capsule of Tenon, but neither the superior nor the inferior oblique can be said to have secondary orbital insertions in the manner in which that term applies to the recti, and such fibers of connective tissue as do pass outward from these muscles in the direction of the orbit are of no clinical importance.

§ 18. **General Plan of the Arrangement of the Connective Tissue of the Orbit, Especially the Capsule of Tenon.**—When describing the secondary insertions of the recti, it was necessary to refer to the capsule of Tenon and the check ligaments. So much confusion exists in regard to them, and their clinical importance is so great, that we must understand exactly what is meant by those terms, and incidentally glance at the general arrangement of the connective tissue within the orbit. It is impossible to consider all the varying descriptions of the so-called "capsule of Tenon" given by different anatomists, or by ophthalmologists who evidently were not anatomists.

Suffice it to say, that when Tenon described, about a hundred years ago, what he called a "new tunic of the eye," that description covered a considerable part of all the connective tissue in the orbit. Since then, different anatomists have made and described different dissections of this "tunic," for we must remember that it is impossible, with the naked eye, to decide whether the hair-like fibers which we see extending in various directions are connective tissue fibers or not, and that only an examination under higher magnification than is possible with the dissecting microscope will determine their nature.

The description of the connective tissue of the orbit which is most familiar to French and English readers, is the one given by Motais (B 48) and copied from him by Maddox, Landolt, and other writers on the muscles. These colored illustrations are very beautiful, and such schematic

representations are easily understood, but it must be remembered that they are only diagrams. (Fig. 23.)

Another description of the connective tissue of the orbit is given by Merkel and Kallius in the last edition of Graefe-Saemisch, and one still more complete by Hans Virchow (B 51), which we have already mentioned. But these descriptions differ in detail, for the fact is that dissections as seen with the naked eye or made with the dissecting microscope lead to different results, and therefore different descriptions.

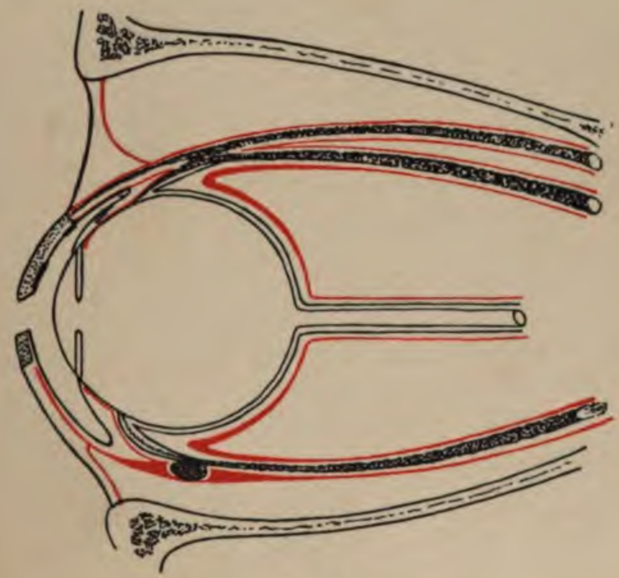

Fig. 23.

Fig. 23.—Schematic representation of the check ligaments according to Motais. Connective tissue in red, muscles in black.

Very recently, however, several selective stains for connective tissue have been found, and one or two of these have assisted materially in demonstrating the arrangement of those fibers near the insertion of the recti, although, unfortunately, the difficulty in photographing colors makes it impossible to show the results except by drawings. After

some experimenting with these stains of connective tissue, I found that some of the most satisfactory results could be obtained with a process in which potassium permanganate was an important factor. A description of this method and of the arrangement of the connective tissue was published in 1902.[1]

It tends to clearness to understand thus the reason for the difference in descriptions, and also where the most recent ones can be found. For our present purpose, when taking only a general view of the arrangement of the connective tissue in the orbit, it is well to view it, as has been done by Motais and earlier writers, as arranged in three layers. The first and most external of these is the periosteum. The anterior portion of this, which is connected with the fascia in that vicinity, is the only part which concerns the student of the ocular muscles, and that only slightly.

The second layer, or the cone of the connective tissue in the orbit, is that which may be said to envelop the muscles as it passes from one to the other. Motais has given some very beautiful drawings of this, but these diagrams do not show the other fibers of the connective tissue which radiate in every direction, especially toward the opening of the orbit, and form a network supporting all the tissues. If a section be made behind the globe parallel to the plane of the opening of the orbit, we see not only the four recti in section, but also the connective tissue surrounding each. The fibers extend from the edge of one muscle in each direction toward the adjoining muscle, thus forming almost a band, and in some of the illustrations given by Motais this looks like a tubular sheath in the orbit, consisting of two layers between which lies the muscles. But that appearance is deceptive, for similar fibers stretch out also in every direction, forming a network throughout the entire orbit, and the bands which go from one muscle to another are only a part of this entire framework. The deeper portion of this second layer is evidently rather of academic interest. But the fibers near the opening of the orbit, where they separate to

[1] *The Connective tissue of the Orbit.* Prize Essay Medical Society of the State of New York, 1902.

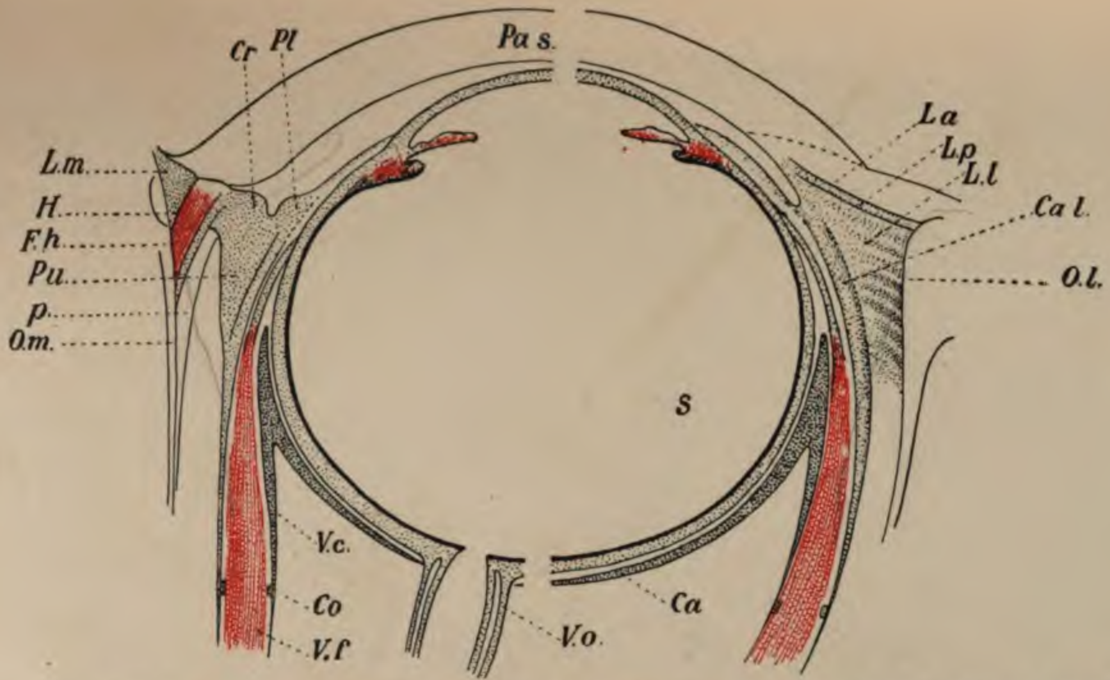

FIG. 24.—Horizontal section through the orbit under threefold magnification. The left or internal half is copied from Hans Virchow (B 51). The outer half is taken in part from his plates and in part from a section in my collection. *Ca*, capsule of Tenon; *Ca l*, layer of the capsule outside of the muscle; *Co*, connective tissue between the muscle and its sheath; *Cr*, caruncle; *H*, muscle of Horner; *L.a.*, the lower edge of the anterior or upper extension of the levator palpebræ; *L. p.*, the lower edge of the posterior or lower extension of the levator; *L. m.*, ligamentum palpebræ mediale; *O. l.*, external or lateral wall of the orbit; *O. m.*, internal or median wall of the orbit; *Pa. s.*, palpebræ superior; *Pl*, plica conjunctivæ; *Pu*, internal support of the capsule; *S*, vitreous; *V. c.*, capsular portion of the muscle sheath; *V. o.*, entrance of the optic nerve.

form the fascia orbito-ocularis and the check ligaments, are of much clinical importance.

In order to show these fibers and the general arrangement of the connective tissue near the opening of the orbit, three diagrams are given, one showing a vertical section (Fig. 23 Motais), another an enlarged horizontal section (Fig. 24, Hans Virchow), and another a horizontal section on a smaller scale (Fig. 25). The last gives a diagrammatic view of these connective tissue fibers near the front of the orbit.

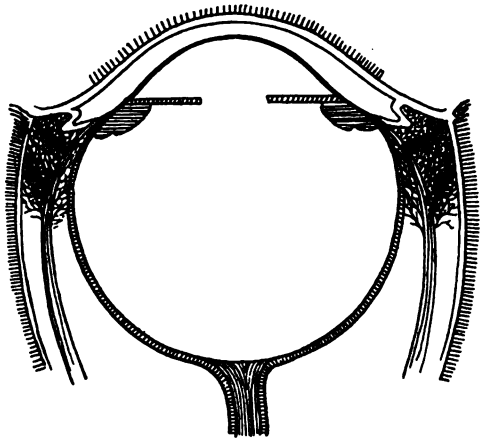

FIG. 25.—Schematic illustration of a horizontal section of the globe. This shows the arrangement of the connective tissue fibers on both sides of the internal and external recti.

The third or innermost layer of connective tissue is more exactly and properly the capsule of Tenon. This layer, commencing posteriorly, where the optic nerve enters the orbit, covers that nerve and then passes forward upon the globe. It is separated from the sclerotic by a space barely perceptible to the naked eye. Across this space fibers pass from the capsule to the globe, holding the two together, yet allowing the globe to rotate within the capsule as in a ball-and-socket joint. The interstices of this space are occupied by a lymphatic network well described by Schwalbe. (B 52.) Where the innermost layer covers the globe proper it constitutes the true "capsule" of Tenon. The concave surface of this capsule can be seen when a vertical section is made through the globe, and it is allowed to fall out of its enclosing capsule. (Fig. 26.)

A question which has been discussed frequently and at length is just how far forward the capsule of Tenon extends —that is, whether it ends *posterior* to the insertion of the recti muscles, or *anterior* to it, and therefore whether the muscles perforate the capsule in order to reach the globe. As a result we have different opinions and ingenious theories in relation to tenotomies and operations for advancement. The fact is that these theories are due largely to a difference of methods in demonstrating the anatomical details, and also to a difference of terms in describing what is then seen. For, as the tendon of the muscle passes to its insertion in the sclerotic it is supported by connective tissue fibers on all sides. If, therefore, these fibers are considered to belong to the *globe*, the capsule may be said to be perforated by the tendon, but if the fibers are considered to belong to the *muscle*—that is, to be offshoots from it, or secondary attachments,—then the muscle may be said to blend with the sclerotic anterior to the capsule.

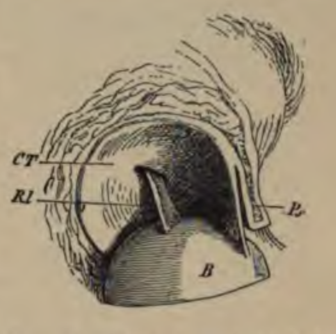

FIG. 26.—Vertical section of the globe. The latter has fallen out of its enclosing capsule, and is held suspended by the conjunctiva anteriorly and by the external rectus muscle (*Rl*) (Merkel and Kallius).

§ 19. **Fascia Orbito-Ocularis and the Check Ligaments.**—Having thus reviewed the general arrangement of the connective tissue inside of the orbit, let us study more carefully that important portion at the opening of the orbit, known as the fascia orbito-ocularis, with the check ligaments.

This fascia may be compared to a curtain stretched across the front of the orbit through which the globe of the eye partly protrudes. The fibers extend from the entire edge of the orbit toward the globe, lying in general just beneath the ocular conjunctiva. They are abundant and thick in some localities, helping to form the check ligaments, and scanty where the fascia is thin.

The fascia orbito-ocularis is easy to demonstrate. If we complete the dissection already outlined, to a point where there remains only a ring of bone around the edge of the orbit, and the globe be then suspended by the optic nerve, an excellent idea is obtained of the fascia. Moreover, if this fascia, when thus stretched out, is examined more closely, it will be observed that at certain parts, especially in the vicinity of the internal and external recti, the connective tissue fibers are thicker and more abundant. These are the check ligaments.

Another and very instructive method of examining the check ligaments is by means of transmitted light. If, with the globe suspended, the specimen is held up before a window, it will be observed that while the entire fascia is translucent, certain portions of it, especially in the vicinity of the recti, are thick and firm. The best view is obtained in a dark room by placing a small electric bulb near to the cornea, and as the light shines through the fascia, the extent and form of the check ligaments are seen with special distinctness. When the entire specimen is suspended the check ligaments, being extended, are thin and long (Fig. 27), but when the bony edge of the orbit is approached to the globe, so as to leave less space between them, the thickened part of the fascia is somewhat quadrilateral in shape, its longer side resting on the bone. (Fig. 28.)

Let us now look more closely at three or four portions of the fascia orbito-ocularis—namely, internally, externally, below, and above the globe,—which have been called the check ligaments.

The internal check ligament is that irregular quadrilateral thickened portion of the fascia which passes from the median surface of the internal rectus to the crista lacrymalis. Its ocular attachment is continuous with the connective tissue which envelops the globe more or less completely, and which constitutes the anterior part of the capsule of Tenon. Indeed, the fibers of the connective tissue interlace so completely that the ocular portion of the fascia orbito-ocularis is really the same as the capsule itself. The median end of

the check ligament is attached along the posterior border of the crista lacrymalis for a distance of ten or twelve milli-

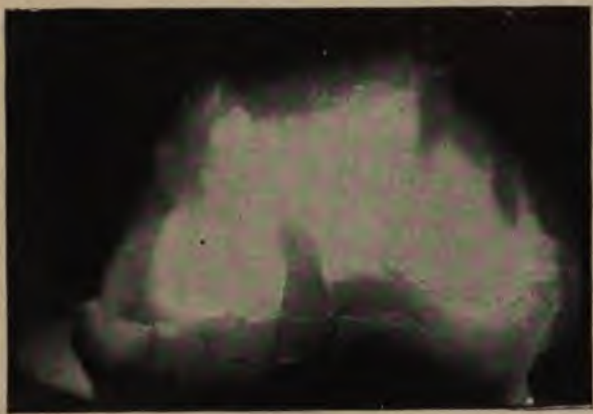

FIG. 27.—The fascia orbito-ocularis extended and viewed by transmitted light. This illumination is produced by placing an electric light behind the connective tissue bands.

FIG. 28.—The fascia orbito-ocularis lighted from behind. The connective tissue fibers are relaxed by allowing the globe to approach nearer the edge of the orbit.

meters. This median limit of the internal check ligament is therefore well defined. Above and below, however, the fibers of the ligament blend gradually with the other portions of the fascia orbito-ocularis.

The external check ligament is made up of the thickened bands of the fascia orbito-ocularis which pass from the external rectus to the margin of the orbit. Its limits are not quite as clearly defined as those of the internal check ligament. Still, this thickened portion is sufficiently well marked to form also a quadrilateral band, the outer margin of which is attached to the margin of the orbit, and the inner edge to the connective tissue on the outer surface of the external rectus. Toward the upper and lower edges of this ligament the fibers blend with the adjacent parts of the fascia orbito-ocularis.

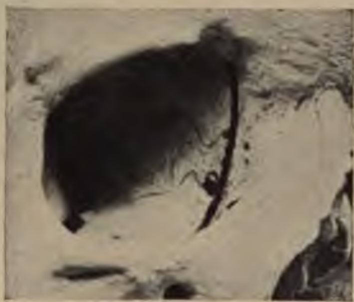

FIG. 29.—Photograph of the inner wall of the orbit. The attachment of the internal check ligament is along the center of this black line.

The inferior check ligament is another part of the fascia

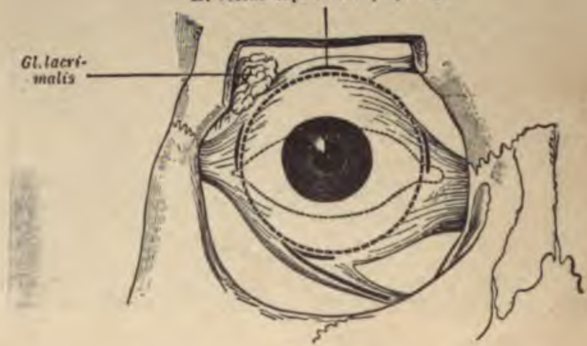

FIG. 30.—Schematic representation of the fascia at the opening of the orbit The upper edge of the orbit has been removed to show the band of fasc. which passes from its inner and upper edge to the globe (Merkel and Kallius)

orbito-ocularis, which is particularly thickened over the insertion of the inferior rectus. In this case the general direction of the fibers is not from the globe toward the edge

of the orbit, as is the case with the two check ligaments already described, but below the globe the fibers pass rather in the direction of the inferior oblique muscle—in fact, they form its anterior covering. Moreover, they tend to arch around the lower portion of the globe, and for that reason they received long ago from Lockwood (B 46) the name of the *ligamentum suspensorium oculi.*

The superior check ligament has also been described as a separate part of the same fascia. It is true that the fibers of the connective tissue in the vicinity of the superior rectus are also thickened, and to that portion the name check ligament may be applied, but the limits of this ligament are not so well defined as are those of the other thickened parts of the fascia. In reality, however, the fascia at this point, being connected firmly to the orbit and to the superior rectus, does also constitute a check upon the rotation of the globe, and in that sense it forms a real check ligament.

Mention of the check ligaments will recall to the reader the illustrations and diagrams by Motais already given. It will be remembered that a horizontal section of the internal check ligament, for example, is represented as similar to the letter Y, one arm being attached to the edge of the orbit, the other arm to the globe, their junction being continuous with the surface of the muscle. While this is true in a rough way, we must remember that the outer arm, for example, is not formed of a single firm band, but of other fibers of connective tissue also springing from the orbit somewhat farther back than the main line of origin. Nor is there any single group of fibers which come in one small band from the globe as represented in transverse section by the internal arm of the letter Y, as this portion is made up, instead, of numerous bands of fibers, already described as the orbital secondary insertion of the recti.

§ 20. **Surgical Anatomy of the Check Ligaments.**—Before leaving this part of the subject let us take up one or two questions concerning the check ligaments which relate rather to surgical than to descriptive anatomy. First: Are these entitled to the name check ligaments? Yes, any one can satisfy himself of this who will take the

trouble to make the suitable dissections. If, after the dissection is almost completed, the cornea be rotated toward the nose by traction on the internal rectus, a point is soon reached where the motion is impeded by tension made on these ligaments; if, then, the ligament be divided, the cornea can then be turned much farther inward. In fact, with sufficiently free division of the ligament, the position of the cornea can be almost reversed.

Again, exactly to what extent does this act as a check in the lesser movements? A very careful study of this question has been made by Motais, and his conclusions are copied in most of the text-books. Briefly stated, they are to the effect that when a muscle begins to contract it makes little or no traction upon the orbital arm of the "Y" ligament, but, as the contraction becomes greater, it draws more and more upon that end of the Y, until the latter becomes so tense that it does not permit any further contraction. After making the dissection described by Merkel and drawing on first the internal and then the external rectus, it seemed that the

FIG. 31. — Check ligaments when the eye is in the primary position. Modified from Motais.

FIG. 32.—Check ligaments during partial contraction of the external rectus. Modified from Motais.

FIG. 33.—Check ligaments during extreme contraction of the external rectus. Modified from Motais.

changes in the position of the check ligament should not be represented as they are usually, but as in the

accompanying diagrams modified from Motais. (Figs. 31, 32, and 33.)

Finally, how far can the check ligaments be extended? Inasmuch as muscles like the recti in other portions of the body can sometimes contract about one half their length, we would naturally expect the maximum contraction of the internal rectus, for example, to rotate the center of the cornea inwards through an arc corresponding to half the length of that muscle. In practice, however, we know that this is out of the question, the difference being partly due to the restraining action of the check ligaments.

§ 21. **Supernumerary Muscles of the Orbit.**—So little mention is ordinarily made of the supernumerary muscles that one not accustomed to dissections may be surprised perhaps that such muscles exist. But any one who has observed the variations in the secondary insertions in different individuals, or who knows how the bands of connective tissue in different parts of the orbit vary in their distribution, can easily understand how these bands may be sufficiently marked in certain cases to be described as special muscles.

For it must be understood that none of these supernumerary muscles approaches in size the other extrinsic muscles, but that they consist only of bundles of striped muscular fibers interwoven with connective tissue fibers.

1. **Muscle of Horner.**—Among these supernumerary muscles, attention should first be called to the muscle of Horner. This is seldom mentioned in descriptions of the contents of the orbit, yet it is often of considerable importance in connection with the operation for tenotomy of the internal rectus. Although described first by an American, W. E. Horner (B 64), one of the best representations of it is given by Hans Virchow (Fig. 24) in the monograph already referred to (B 51). The muscle consists of a few bands, which arise from the crista lacrymalis posterior and pass horizontally forward and somewhat outward, to be inserted into the tissue just anterior and to the inner side of the caruncle. Farther anteriorly, they pierce the network of connective tissue to be inserted into the conjunctiva and

the adjacent structures. The function of this muscle is not well understood. Possibly it is the remnant of the band which moves the nictitating membrane in the lower animals, or it may assist in facilitating the flow of tears away from the globe. However that may be, the direction of the fibers shows without question that it also tends to draw the conjunctiva inwards and backwards as long as the orbital fascia is in its natural position. While the action of Horner's muscle is thus difficult to see in the normal condition, yet when the fascia is disturbed to any great extent, as in lacerations such as follow certain forms of tenotomy, the fibers of this muscle, then, having nothing to counteract them, draw the conjunctival tissue in and backward, and we have a sinking of the caruncle, with the consequent deformity.

2. **The Gracillimus or Transversus.**—At quite an early date careful anatomists recognized at least one or two other supernumerary muscles—these lying near the roof of the orbit. Albinus was probably the first to describe one of them. He found a band passing from the levator with connections inward, especially to the superior oblique, and this muscle he called the gracillimus.

Another description of the gracillimus, or of a band similar to it, is in an article by Bochdalek (B 70). He found this additional muscle in both orbits of one subject. These differed slightly from the gracillimus described by Albinus, and also differed somewhat from each other.

A more careful search for the gracillimus, or a muscle similar to it, was made by Budge (B 63) of Greifswald. He says "While making preparations of the muscles of the eye, I found a muscular portion given off from the levator palpebræ superior. This portion branched into two small bundles, from the inner side of that muscle, and then, passing inward, they were inserted into the trochlearis." He examined about twenty orbits of children and grown persons, as to this point, and there were only five without some traces of these fibers, although in some instances they appeared to be hardly more than threads. Among the muscular bands found by Bochdalek in the upper portion of the orbit he describes another as the anomalous trans-

versus. (Fig. 34.) He says it arises from the anterior and upper portion of the orbital plate of the ethmoid, and passes almost directly across the upper part of the orbit. At its origin it consists of small tendinous bands 3 to 4 mm. in thickness; these, enlarging into fleshy bundles, give off various attachments to neighboring fascia, and especially to the levator palpebræ. In fact, when the transversus is small it forms practically a part of that muscle.

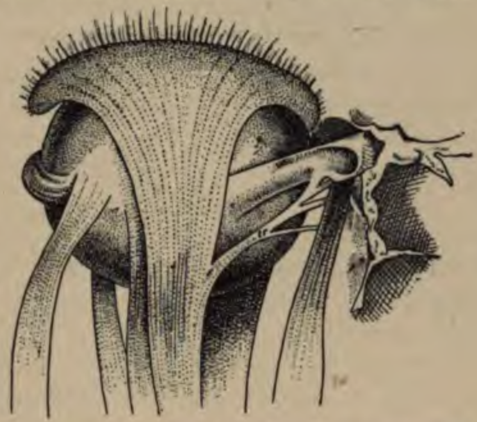

FIG. 34.—Supernumerary muscle, the transversus (Tr.).

Other supernumerary bands, more or less abundant in muscular fibers, have been met with in the orbit, and are mentioned in the literature from time to time (B 54 to 72), some of the writers being apparently ignorant of the observations made by others. It is quite certain, therefore, that these additional fibers are more common than the usual descriptions would lead us to expect. Even in a small collection of orbits there are usually one or two which illustrate very well the presence of these minute muscular bands. Usually, these are what might be termed supporting fibers, which are more or less continuous with the muscle, and which run in the same direction. Sometimes, however, they are quite distinct, passing in the direction, not of the fleshy portion of the muscle, but rather of its tendinous expansions. A good example of this is found in the striated fibers often present in the upper and outer portions of the orbit, in the region where the external bands of the levator bend outward or even partly backward, to be lost in the tissue of the orbit near the lacrymal gland.

Although we are considering at present only questions of

anatomy, we may turn for a moment to the probable functions of these fibers. If we judge of the action of a muscle from its point of origin and insertion, we must infer that the larger of these, the gracillimus or transversus, assists the levator,—as, for example, in the act of winking.

§ 22. **Influence of Heredity on the Ocular Muscles.**—Recent studies show more and more the tendency of the offspring to resemble the parent even in the most minute details of structure. This is particularly noticeable in certain parts of the eye. Perhaps one of the best examples is in the curvature of the cornea. We find occasionally in parent and child an astigmatism with the degree and the axis wonderfully similar. When we remember that this means a reproduction in the child of the curvature of the parent's cornea even to a fraction of a millimeter, we begin to realize the far-reaching effects of this law of heredity. A comparatively slight consideration of the subject leads one to think also that we have not given to this subject the attention it deserves, when studied from the standpoint of the ocular muscles. It is a common observation to find that there is an hereditary tendency to certain forms of heterophoria. Most practitioners also have met with families in which there are two, three, or more cases of abnormal convergence. This same tendency is shown in the transmission through successive generations of peculiar types of nystagmus and especially certain forms of ocular paralyses. Apparently no one has thus far made systematic measurements of the attachments of the recti in such cases, but inasmuch as different members of squinting families often apply to the same surgeon, and as it is possible to make quite accurate measurements of the primary insertions of the recti immediately after certain forms of tenotomy, it would seem that this question might be easily studied. In this connection we are reminded of the contention made years ago by Stevens, that races and individuals who have long, tall skulls have also, as a rule, a tendency to quite a different position of the visual axes than those who have short, broad skulls, and that these positions of the axes necessitate abnormal traction of certain muscles. It is probable that

some such tendencies do exist. But as the conclusions thus far reached are based on apparently insufficient measurements, it still remains for others to study this question and the general influence of heredity on the ocular muscles.

CHAPTER II.

THE INTRAOCULAR MUSCLES AND OTHER STRUCTURES CONCERNED IN ACCOMMODATION.

§ 1. **The Intraocular Muscles.**—In most chapters on the ocular muscles comparatively little attention has been paid to the act of accommodation. The more one studies the subject, however, the more evident does it become that the structures involved in this act are, from the clinical point of view, quite as important as the recti and obliques. The intraocular and the extraocular groups are as essential to each other as are the blades of a pair of scissors. The fact that the ocular muscles have been viewed in former monographs almost entirely from the standpoint of the extraocular group was one of the reasons for undertaking this study.

In order to understand more exactly the mechanism of accommodation it is necessary also to recall some anatomical details relating to the structures by which that act is accomplished.

(A) The Ciliary Muscle.—When an antero-posterior section of the ciliary region is viewed under even slight magnification, it is easy to see that the muscular fibers may be divided into three groups, as was first described by Iwanoff (B 79).

The outer or meridional layer is composed of fibers which lie next to the sclerotic, and whose general direction is almost parallel to the latter. They appear to arise near the periphery of the iris, and passing backward close to the

sclerotic become continuous posteriorly with the choroid at and beyond the ora serrata. In the center, this layer of fibers is about a millimeter in thickness, but it is thinner posteriorly, where it becomes flattened into a delicate mesh interwoven with the choroid. In other words, we may consider the fibers of this layer as attached anteriorly to the periphery of the iris and to the sclerotic, and posteriorly to the choroid.

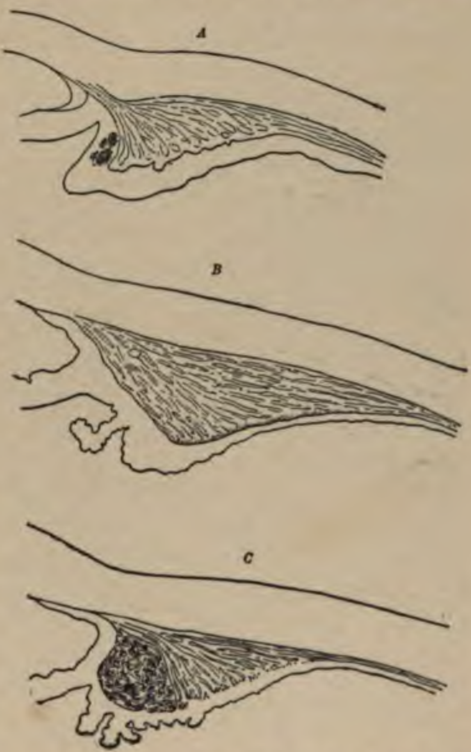

FIG. 35.—Transverse section of the ciliary muscle. (*A*) emmetropia, (*B*) myopia, and (*C*) hypermetropia. (Iwanoff.)

The second, or radial portion lies more internally. The fibers, viewed in section, are seen to spring from the same point anteriorly as those of the outer layer, to pass backward not quite so nearly concentric with the curve of the sclerotic, but spreading out toward the center of the eye in the shape of a fan whose external edge is longer than the internal one. (Fig. 35.) There is no line of demarcation between the middle group of fibers and those external or internal to it. The size and extent of this portion vary. In the hypermetrope, the fibers pass more directly backward, while in the myope they are more nearly parallel with the fibers in the first group—namely, the meridional fibers. The radial fibers of the ciliary muscle do not

appear to have as definite an origin as do those in the first or outer group. They interlace with each other, pass backward, and at their posterior extremities give attachment to the fibers of the zone of Zinn.

The third group of fibers which compose the ciliary muscle consists of circular fibers lying just within the radial group. It is generally known as the muscle of Müller or of Bowman, but Wallace of New York (B74) was apparently one of the first to demonstrate these fibers and the ciliary muscle as a whole. When these circular fibers are viewed in cross-section they appear as mere points. In the hypermetropic eye these points are numerous, but in the myopic eye, especially in the higher degrees, Iwanoff considers that they are lacking entirely.

FIG. 36.—Dilator pupillæ. Antero-posterior section. Magnification 250. (Verhoeff.)

These three groups of fibers which, taken together, we call the ciliary muscle, regulate the accommodative changes of the crystalline lens, as we shall see later, and in doing so perhaps contribute more to our comfort and enjoyment than any other muscle of the body.

(B) The Dilator Pupillæ.—This interesting portion of the iris should not be passed without mention, although hardly

more than that is possible here. Its existence was established in the earlier half of the last century, and although many later students could not confirm the observation, we know now that this was due largely to the irregular course of the fibers. One of the best articles on this muscle is by Grunert (B 94), which gives also quite a complete bibliography of the subject. When an attempt is made to reproduce any of these sections by photography, the half-tone representation does not do justice to the specimen. Figure 36 is sufficient to give a general idea of the position and direction

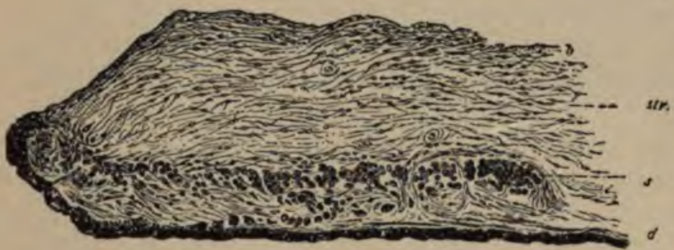

FIG. 37.—Vertical section through iris and ciliary region. Sphincter pupillæ (*s*). The dots representing the fibres in cross-section seem to extend quite a distance from the pupillary margin. This is because of the considerable magnification used. Stroma of the iris (*str*).

of the fibers of the dilator. The section is made from before backwards. The portion on the left is the stroma of the iris (facing the cornea). That on the right is the epithelium of the iris (facing the lens). Between the stroma and the epithelium there can be seen the dark line of fibers which together constitute the dilator of the pupil. With stronger magnification the separate fibers of the muscle can be recognized as if they were the spokes of a wheel whose hub is the pupil. The radiating fibers do not pass straight off toward the periphery of the iris, however, but interlace with adjoining fibers in a more or less irregular network.

(C) The Sphincter Pupillæ consists of a band of circular fibers which is situated in the iris near the edge of the pupil

and concentric with it. These fibers lie in the stroma of the iris, just at its pupillary margin, considerably nearer to the posterior than to the anterior surface. They are seen in section in Fig. 37 (*s*). An examination of the sphincter under rather high power shows that the different parts lie close together and are interwoven, each bundle of fibers being supplemented by others near to it, so that together they act as a single muscle to contract the pupil.

§ 2. **Suspensory Ligament of Zinn—Zonula Zinnii.**—The foregoing consideration of both the extraocular and intraocular muscles might perhaps be deemed sufficient for our purpose. But the important act of accommodation is greatly modified by what we may call the "resistance" offered to the ciliary muscle by any rigidity of the lens, by any astigmatism present, or by other imperfections of the refracting media. If, therefore, we wish to have a proper appreciation of the work done by the intraocular muscles we must see in what this so-called "resistance" consists. In other words, we must consider, at least briefly, the manner in which the ciliary muscle is attached to the lens, we must glance at its structure, its imperfections — especially in the production of astigmatism—and other causes of "resistance" which may exist.

This zonula is usually described as arising from a certain special part of the ciliary process, and then dividing into two layers, one of which passes over the anterior and the other over the posterior surface of the lens. It was supposed that these two layers compressed both sides of the lens, or relaxed their pressure equally in the changes of accommodation. More recent studies, however, have shown that the structure of the ligament is not so simple, nor do the sides of the lens change equally. When we examine the zonula in section we find it to be composed of very fine fibers which are either transparent or highly refractive. They do not arise from any one part of the ciliary process, but along its entire inner aspect. The fibers which arise from the part nearest to the iris pass almost directly to the anterior surface of the lens. Those which arise more posteriorly,—that is, from the ends of the more distant radial fibers,—also

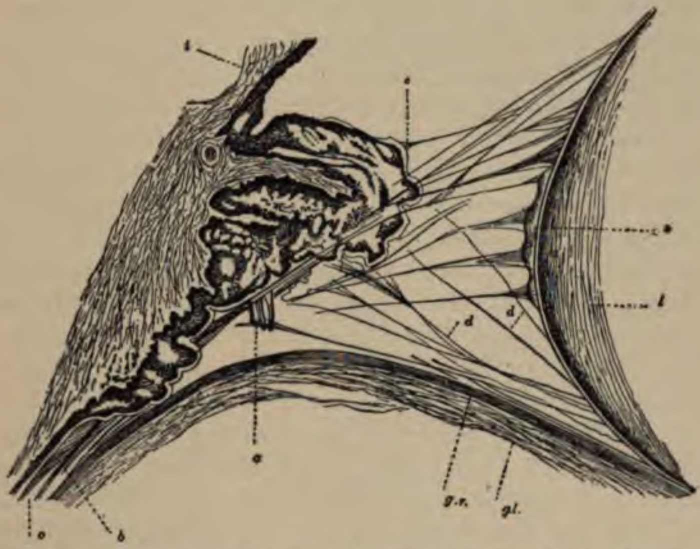

FIG. 38.—Vertical section through the ciliary region (Retzius). The fibers which constitute the zone of Zinn (*d*) stretch from the ciliary processes to the lens. The figure shows the direction and arrangement of these fibers; also the manner in which the posterior fibers, especially, have secondary attachment fibers, as in (*a*).

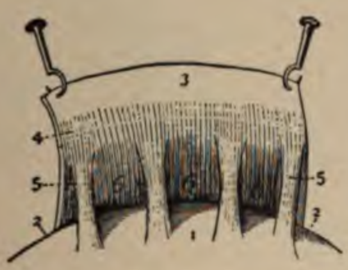

FIG. 39.—Diagrammatic view, from posterior surface, of the insertion of the zone of Zinn into the capsule of the lens (Testut). 1. Posterior lens surface. 2. Its equator. 3. Zonula. 4–5. The anterior and posterior bands. 6. The inter-fascicular spaces, formerly regarded as the canal of Petit.

FIG. 40.—Fragment of capsule of lens near its equator. The points reflected backward are the attachments of the zone of Zinn (Schoen).

pass for the most part over the anterior surface, while those which arise still more posteriorly interlace with the adjoining fibers and pass partly to the anterior and partly to the posterior surface.

This interlacing of fibers of the ligament is not easy to photograph, the fibers seldom lying in the same plane. A drawing by Retzius is reproduced here. (Fig. 38.) The physiological importance of this arrangement is evident, for since certain special portions of the zonula arise from certain portions of the ciliary process, it is easy to understand how, in accommodation, the anterior surface of the lens may become relatively more convex toward the center, while the posterior portion may remain unaffected. Another schematic view of the zonula is given in Fig. 39 from Testut and also a part of the capsule near the equator of the lens in Fig. 40 from Schoen.

§ 3. **Structure of the Lens.**—We know that the laminæ which make up the lens bend over its edge like the layers of a flattened onion. This can be easily seen by boiling a

FIG. 41.—Boiled lens enlarged and viewed from the edge.

FIG. 42.—Some of the layers of the lens separated from each other (Fr. Noland).

fresh lens (Fig. 41). A vertical section of the different layers is shown in Fig. 42 and also in Fig. 43. When one of these layers is examined more minutely we find that it is composed of so-called ultimate fibers, each one fitting ac-

curately to the next. (Fig. 44.) As these ultimate fibers pass from one side over the edge of the lens to the other side, it is natural to conclude that their elasticity produces a constant tendency in each fiber to stretch out more nearly straight. We should remember also that the superficial layers are by no means as dense as those near the center. Indeed, the lens may be considered as made up of several strata, each composed in turn of a number of ultimate fibers, the external strata being decidedly more elastic, and having a lower index of refraction, than those which lie near the center.

The foregoing account of the structure of the lens accords in general with that

FIG. 43.—Vertical section of the lens showing its laminæ (Merkel).

FIG. 44.—Ultimate fibers of the lens (Merkel).

which is found in most of the text-books or digests of physiological optics. But such a description has one great fault. The student is led to believe that when parallel rays fall on the lens they all converge to a single point, and therefore that the work done by the ciliary muscle, whatever that may be, is comparatively simple. In reality, however, such is not the case. We must, therefore, take into account these imperfections of the lens, for, as we shall see, they indicate that a complicated action of the ciliary muscle is necessary in order to produce a more or less perfect image. Let us glance at a few of these peculiarities.

First are the irregularities in the structure of the anterior surface of the capsule,— the *chagrin* or roughness

of the lens. (Fig. 45.) This can sometimes be seen imperfectly by illuminating the lens obliquely and examining the spot thus lighted through a strong loupe. It can also be made visible with the large horizontal microscope, but the best view of it is obtained with the corneal microscope of Zeiss. When seen in this way, the anterior capsule presents a roughened, irregular aspect, not unlike the paper or linen which covers the pasteboard binding of certain books. This appearance is called technically the "chagrin" of the finish, and this term was used also to describe the roughness of the anterior capsule by Hess, one of the first to observe it. It is shown in Fig. 45. Any one who will take the trouble necessary to see, in this way, how irregular the surface of the capsule really is, is inclined to regard this condition as one of the reasons why the lens does not always give a perfect focus.

FIG. 45. — Appearance under magnification of the anterior surface (the chagrin) of the lens.

A second imperfection is the fine radiating opaque lines which quite often exist *near the periphery* of the lens. Every practitioner is familiar with the appearance presented by a so-called peripheral cataract in the early stages. Even with an undilated pupil it is then easy to see by reflected or transmitted light how the fine lines in the lens streak toward its center. Now when the pupil of even a normal eye is moderately dilated, it is usually possible to distinguish similar lenticular opacities, especially when the person has passed early life.

Third, fine opaque lines, irregularly radiating or branching, are nearly always present *near the center* of the lens. These apparently correspond to the *raphes* produced by the joining of the ultimate fibers, which, after starting from such a line near one surface of the lens, bend over its edge to form this line on the other surface. Various forms of

these lines are shown in Fig. 46. They were studied carefully by Friedenberg, and can be seen subjectively, as he saw them, by simply looking through a minute aperture. The coarse stenopaic disc, which comes in the usual test case,

FIG. 46.—Five samples of entoptic spectra as seen in different eyes, these sectors being caused by the radiating lamellæ (Friedenberg).

has an opening too large to make this observation accurately. The best way to see these central lines entoptically is to make an opening with a very fine needle in a sheet of copper which has been rolled out to the thinness of writing-paper. Holding this with the hand—or better, fixing it in a test frame,—one should look through the small hole at the sky, the other eye meanwhile being covered. A stenopaic disc of this kind is not simply an instrument to be kept in the test case, but is of real use. For when the

FIG. 47.—Two entoptic spectra in eyes which have perfect vision. These were seen when the person looked at the sky through a smooth stenopaic opening half a millimeter in diameter (Hess).

lines and the spots (which will be mentioned next) are especially abundant or well marked, they mean a difficulty or impossibility on the part of the ciliary muscle to produce a perfect focus, and therefore a more unfavorable prognosis of any existing asthenopic symptoms must be given.

Fourth, one or more *small spots* in the lens are usually

seen by these subjective tests. Ordinarily one is quite apparent, near the center of the lens, and toward it the radiating lines converge; or that spot, or a second, or possibly still another, barely perceptible and more or less eccentric, can be detected with patience in changing the position of the opening before the eye and by altering the degree of the accommodation.

§ 4. **Position of the Lens.**—We are apt to think that the axis of the lens coincides with the optic or the visual axis. The fact is that the lens usually faces temporalward in relation to the visual axis and usually its upper edge is tipped forward, or it is otherwise displaced slightly from the position which it is usually supposed to occupy.

Now this tipping, or malposition of the lens, not only produces in itself a slight amount of astigmatism (Fig. 48),

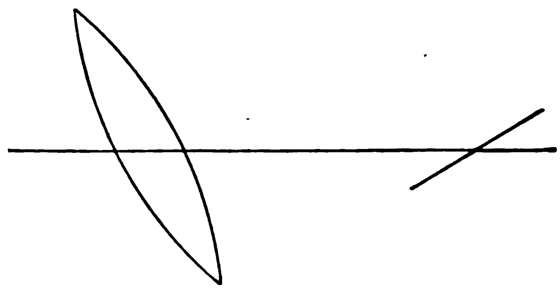

FIG. 48.—The focal line of a lens which is placed obliquely (Tscherning).

even in what we call the normal eye, but clinical experience indicates that in many instances even a comparatively small degree of malposition of the lens requires such traction on the ciliary muscle as to be an important cause of what we call accommodative asthenopia. Since making it a habit to measure the position of the lens, I have been impressed by the number of cases in which discomfort and symptoms of asthenopia were associated with an unusual degree of this malposition. It is difficult to say why astigmatism produced in this way should give any more inconvenience than an ordinary corneal astigmatism, although, if additional theories were desired concerning the unequal traction thus made directly upon the fibers of the ciliary muscle, it would

be easy to build one up. In any persistent case of asthenopia, no examination can be considered complete unless the position of the lens with regard to the axis of vision is also taken into account. We must therefore examine with considerable care the methods by which the malposition of the lens can be measured. In doing so let us glance at the simple principle involved, as illustrated by a familiar experiment, and then see how that principle is worked out in the instruments ordinarily used to measure the position of the lens.

§ 5. **How can we Determine the Position of the Lens?** —Let us begin by observing the relative positions of the reflections from its surfaces (the so-called entoptic images) as compared with the position of the reflection from the cornea. This is not difficult. The reflections from the cornea and the posterior surface of the lens are readily seen when, in a dark room, we look in to the pupil of an eye upon which the light from a candle falls obliquely. (Fig. 49.) We see

FIG. 49.—Relative position of observed eye (*A*), of the light (*C*), and of the observer's eye (*B*) during examination of the entoptic images (Helmholtz).

from the cornea the reflection of the candle flame conspicuous and comparatively large, and from the posterior surface of the lens a bright point much smaller than the first. If we then look with much care, and just at the proper angle, we may also see the blurred irregular reflection from the anterior surface of the lens. That, though, is more difficult to recognize, and may be disregarded for the present.

The point of interest to us is the relative position of the reflections from the cornea and from the posterior surface of the lens. If, in a dark room, the observer were to look

straight into the observed eye and the patient were to look straight back at the observer, the visual axes of both coinciding, and if at the same time a candle were held slightly above or below the observer's eye, he would see the reflections from the cornea and from the posterior surface of the lens in the same vertical line, provided the axis of the lens thus looked at coincided with its visual axis.

But if the lens in the observed eye faced outward or inward a little, then under the same circumstances the observer would see these two reflections arranged as in Fig. 50 *a*. In reality, this is what we do find almost invariably

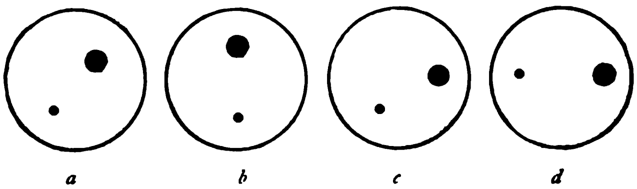

FIG. 50.

FIG. 50 *a*.—Reflections from cornea and posterior capsule when the lens is tipped outward (its usual position).

(*b*)—Reflections from cornea and posterior capsule when the lens is in vertical alignment.

(*c*)—Reflections from cornea and posterior capsule when the lens is tipped forward.

(*d*)—Reflections from cornea and posterior capsule when the lens is in horizontal alignment.

when this examination is made by a more accurate method presently to be described. Evidently it is not difficult to ascertain how much this lateral malposition of the lens amounts to, for if the lens faces temporalward, as usual, and the observed eye be rotated slowly toward the median line, a point is found at which the reflections from the cornea and from the posterior surface of the lens do come into the same vertical line as in Fig. 50 *b*, and the number of degrees thus traversed horizontally by the globe is, of course, the number of degrees which the lens faces outward.

Or it may be that the lens tips vertically. In that case,

if the candle were held directly below or above the line connecting the foveæ of the observer's and of the observed eyes, the reflections from the cornea and from the posterior surface of the lens might still be in the same vertical line. But if the candle were held at the side, the two reflections would stand as in Fig. 50 *c*. Then, if the observed eye were turned slowly up or down, a point would be found where the two reflections would stand in the same horizontal line (Fig. 50 *d*), and the number of degrees thus traversed up or down by the globe would be the number of degrees of vertical tipping of the lens.

This examination of the reflexes with the candle only, is sufficient to illustrate the principle involved. If accuracy is required, some arrangement must be devised for holding and changing at will the position of the light, and for viewing the reflections, preferably under magnification, as with a telescope. A movable arc must also be provided on which to measure the amount which the globe is rotated in any given direction. Such an instrument, very complete in its details, has been designed by Tscherning and called by him an ophthalmophacometer. But before examining it let us study for a moment a modification of the ophthalmometer which I have found would serve practically the same purpose.

§ 6. **A Modification of the Javal Ophthalmometer for Estimating the Position of the Lens.**—As the instrument devised by Tscherning is rather large and complicated, and as nearly every ophthalmologist has some form of the Javal ophthalmometer which contains the essential parts of the former instrument, it seemed that the ophthalmometer might be so modified as to make it serve the purpose of Tscherning's ophthalmophacometer.

This is done as follows:

First. The inner sheath of tubing which holds the prism in the barrel of the instrument is removed, and arranged so that it can be withdrawn or slipped back into place when desired, as a cartridge is slipped into the barrel of a gun. A slot in the rim of the outer tube, corresponding to a projecting pin on the cartridge of prisms, holds the latter

exactly in position (Fig. 51) when it is desired to use the instrument as an ophthalmometer, or when the prisms are removed the instrument becomes a simple telescope.

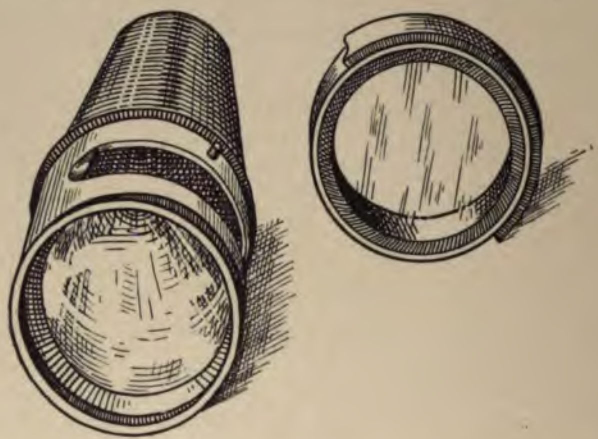

FIG. 51.—Arrangement by which the prisms can be removed from the Javal ophthalmometer, thus converting the instrument into a telescope for determining the position of the lens.

Second. A small electric light is placed six or eight centimeters below the center of the arc, turning when the arc turns. (Fig. 52.)

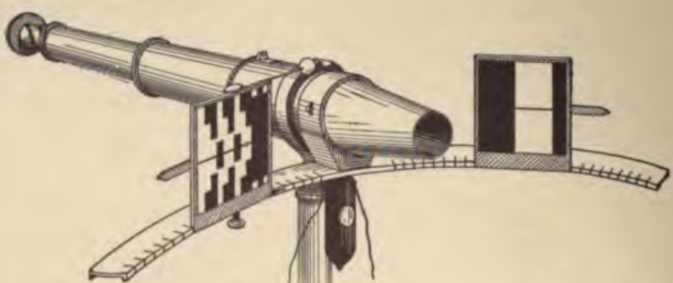

FIG. 52.—Arrangement of the Javal ophthalmometer when converted into a telescope with a light below and a movable point of fixation (a glass ball) above, for determining the position of the lens.

Third. A small glass ball (a hat pin) is attached horizontally to the top of one of the mires, the conspicuous head

serving as the point of fixation. In order to use the ophthalmometer as an ophthalmophacometer, the cartridge containing the prisms is removed, the lights illuminating the mires are extinguished, the single small electric lamp is lighted, the patient's head placed in the rest in the ordinary manner, and he is directed to look at the fixation point, which is placed at first just above the barrel of the instrument. When this is done, the observer sees the reflection of the light on the cornea (magnified by the telescope), and below, and usually toward the inner side, there is a smaller bright reflection from the posterior surface of the lens. The reflection from the anterior surface of the lens cannot be seen at the same time because of the short focal distance of this telescope (the ophthalmometer). The position of the visual axis and the axis of the lens is seen in Fig. 53 and also the relative position of the reflections from the cornea and from the lens. If the small glass ball be now

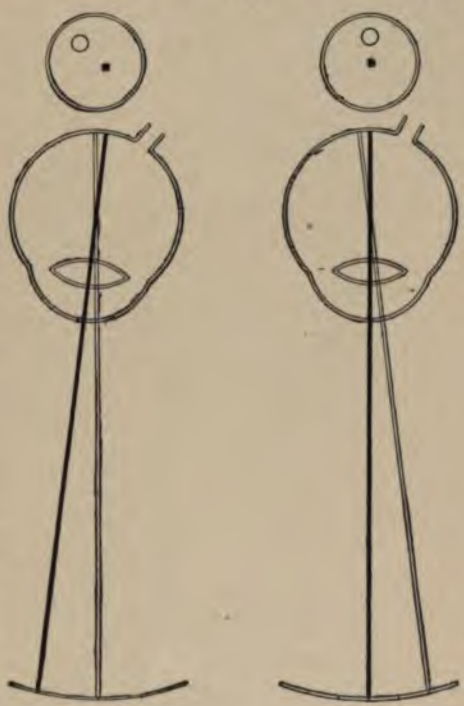

FIG. 53. FIG. 54.

Relative position of the entoptic images.

FIG. 53.—When the observer sights along the lighter line into the right eye, for example, of the patient, he finds the entoptic images are usually *not* in the same line.

FIG. 54.—When, however, the patient has turned his eye through a sufficient arc to the left, so that the observer looks from the same point along the heavy line, then those images *are* in a vertical line, if the lens is not otherwise displaced.

slid along the arc of the instrument, a point is reached at which the reflections are in the same vertical line (Fig. 54). The angle can then be read off on the arc, as the amount which the lens turns temporalward. In other words, *this is the angle alpha.* If we wish to measure the amount which the lens tips forward, the light and point of fixation are placed horizontally by turning the arc vertically, and the measurement made as before.

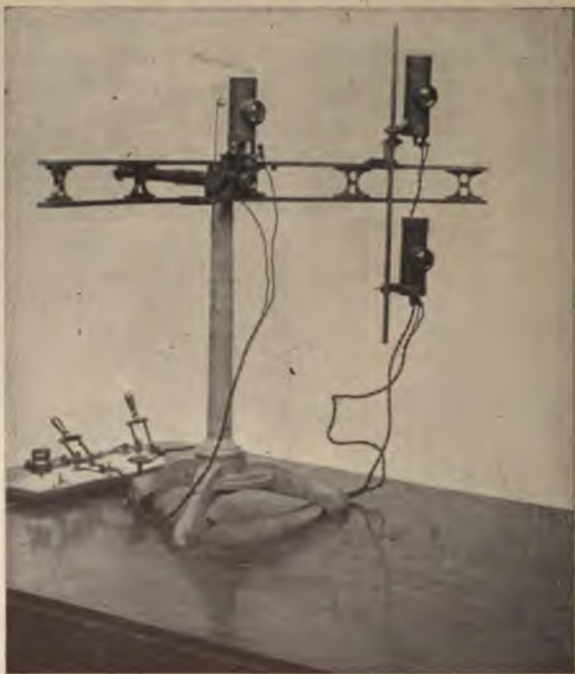

FIG. 55.—Ophthalmophacometer of Tscherning. The arc horizontal.

When the ophthalmometer is thus altered into an ophthalmophacometer, it does not make as complete an instrument as the ophthalmophacometer of Tscherning, but it is simple, it is convenient, and quite sufficient for all clinical purposes.

§ 7. **The Ophthalmophacometer of Tscherning.**— If we wish to ascertain not simply which way the lens is tipped, but exactly how far it lies behind the cornea, and especially

if we wish to observe the changes in its two surfaces during accommodation, it is necessary to use the ophthalmophacometer of Tscherning. (B 264.) (Figs. 55, 56.) The principle involved, however, is just as simple as in the examination of a lens with a candle, or with the modified ophthalmometer just described. The base of the ophthalmophacometer is

FIG. 56.—Ophthalmophacometer of Tscherning. The arc vertical.

a heavy tripod, supporting a pillar of iron about fifty centimeters high. On the top, a telescope is firmly fixed, which has a focal distance of about eighty-five centimeters. The telescope as described by Tscherning has a magnifying power of about twelve diameters, but it gives an inverted image. This inversion is very confusing, however, and requires the observer to make a mental transposition of

reflections is similar to that seen in Fig. 58. Or, if these reflections are watched during the act of accommodation, the changes in their relative positions are complicated and not always possible to explain. A consideration of those changes would lead us too far from our object at present,

FIG. 59.—Reflections from same two lights when the lens is in alignment, (Tscherning).

which is to ascertain simply the malposition of the lens and just how much it is tipped on the vertical or the horizontal, or on an oblique axis.

§ 8. **Other Refracting Media which may Influence the Ciliary Muscle.**—Evidently these are the cornea and the vitreous. Let us consider them in order.

(A) *The Cornea* is too often considered clinically as a membrane whose curvature is equal in all directions. Or when we measure that curvature with the ophthalmometer and find an astigmatism, we are apt to infer that an irregularity of the same degree extends to every part of the cornea. Now the fact, frequently forgotten, is that with the ophthalmometer we really measure only the curvature of a very small area near the center of the pupil, and although the curvature of the other parts of the cornea usually approaches that of the center, it is seldom or never the same. Sometimes it is quite different. In fact, an eye whose vision is $= \frac{6}{6}$, and whose cornea shows only 0.5 D of

astigmatism in its central portion, will often show twice or three times as much if we make the same measurements farther from the center. The works on physiological optics nearly all refer to this irregularity of the cornea, and its consequent tendency to produce not the perfect focus which we see figured in the text-books, but instead, an irregular crossing of rays with consequent circles of diffusion. (Fig. 60.)

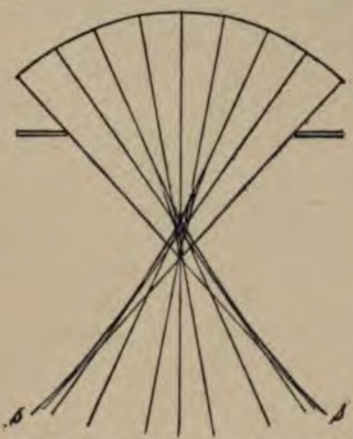

FIG. 60.—Form of the focus which is made by a cornea with comparatively slight degree of unequal curvature near its center (Gullstrand).

(B) *The Vitreous* is seldom clear. Nearly every one who has passed early life can see the muscæ volitantes in his own eyes when he looks through a small stenopaic opening at a bright light, though it is probable that these have usually comparatively little influence upon the exactness of the focus formed.

(C) *Combined Effect of Imperfections of the Media.*—The various imperfections in the refractive media combine to produce an imperfect focus, especially when the pupil is rather large. This important clinical fact is often ignored. It is difficult even for the advanced student to rid his mind of those elementary diagrams which show all the rays coming together just at a single point. It would be better for him to recall another diagram (Fig. 61), even though this shows the rather unusual course which the rays take, especially with a wide pupil. With such a condition as is represented in this diagram, evidently it is impossible to obtain a perfect focus. There may be one or two points where that is fairly good, but clear vision is obtained only by an effort of the ciliary muscle to keep the lens adjusted with reference to a certain point—say *o* or *u*—as may be required for the far or near point. Above all, the sphincter of the

iris must be held disproportionately tense in order to keep the pupil small. The part which the iris and the ciliary muscle play in overcoming these circles of diffusion is familiar to us all in the effect of atropin. It is a common

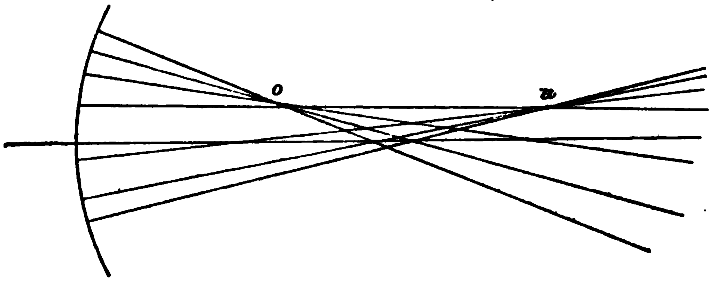

FIG. 61.—Schematic representation of the visual focus, *o* and *u* being special focal points (Hess).

experience to find a young person who has vision of $\frac{6}{6}$ and little or no error in the refraction apparent by simple tests; we apply atropin, the vision falls to $\frac{6}{8}$ or even $\frac{6}{12}$, and we cannot improve it with any glass as long as the pupil is dilated.

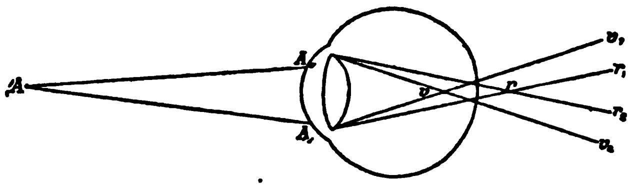

FIG. 62.—Diagram showing the manner in which the chromatic aberration of a human lens corrects itself. In this it will be seen how the red ray, r_1, r_2, from one portion of the periphery, coincides with the violet ray, v_1, v_2, from another portion of the periphery (Hess).

Perhaps we might wonder why it is that such persons do not complain of chromatic aberration and all sorts of similar difficulties. This and like questions have been asked and answered by Helmholtz, Volkmann, Hering, and others. The reason we do not notice the fringe of colors, for example, has been satisfactorily explained by the overlapping of the spectra. Thus, in Fig. 62, as the ray A $A_{,}$ enters the eye, when unequally refracted by any of the media the violet portion is bent toward v_1 and the red por-

tion toward r_1. The ray $A\ A_{\prime\prime}$ is also spread out into v_2 and r_2, but as these circles of diffusion constantly overlap, the red ray falls upon the violet one often enough to correct the impression of chromatic aberration.

In a similar manner, Helmholtz has shown that when the retinal image is imperfect a portion of the impression is suppressed, as it were, following the law of contrasts, and in that way the difficulty is obviated, at least in part. For our purpose it is unnecessary, even if it were possible, to enter into details concerning the correction of chromatic aberration or other imperfections of the retinal image. Suffice it to say that they exist more or less markedly in practically every eye.

§ 9. **Of what Clinical Importance are Abnormal Positions of the Lens or Imperfections of the Refractive Media?**—The question may perhaps be asked, what is there in a study of the muscles of the eye to warrant so much attention to the structure and position of the lens, to instruments for measuring it, and to imperfections of the refractive media? At first glance these topics may seem quite foreign to the ocular muscles. But in the clinical part of our study we must keep constantly in mind the fundamental fact that the whole aim of the ciliary muscle, and secondarily of the other muscles, is to form on the retina as clear a focus as possible. Anything which interferes with that is an element in the *resistance offered for the intraocular muscles to overcome.* For example, we have long ago recognized the fact that even a slight amount of corneal astigmatism does in certain individuals produce very decided asthenopic symptoms, those symptoms disappearing when the imperfection of the cornea is corrected by a suitable glass. But a malposition of the lens can also produce an astigmatic focus. Indeed, that malposition may be of such a kind as to make its optical correction impossible. Evidently such a condition must influence the prognosis very decidedly, and the desirability is apparent of recognizing not only the condition, but its degree. In like manner imperfect foci may be produced by irregularities in the density of different portions of the lens, or by the unequal curvature of its surfaces,

especially in the act of accommodation, or by relatively dense spots either in the lens or the vitreous.

It is only necessary to recall the fact that any one of these imperfections constitutes a factor in what may be called the *resistance* to normal muscular action, and we appreciate immediately that each of these may be, and often is of decided clinical importance.

In this connection it should also be remembered that any irregularities in the curvature of the cornea or of the lens, or opacities in the refractive media which ordinarily do not impede vision because of the contraction of the pupil, do become more noticeable after a cycloplegic has been used. All of this emphasizes the fact that when we use atropin the condition of the refraction then obtained does not represent the actual refraction of the normal eye.

§ 10. **Accessory Muscles of Accommodation.**—Writers have apparently overlooked to a great extent the rôle played by the accessory muscles of accommodation. It is worth while, therefore, to recall them, not only for completeness, but because of their undoubted clinical importance in connection with certain forms of ocular headaches.

The first of these accessory muscles is the *corrugator supercilii*. According to Gray, this is a small pyramidal muscle placed near the median line, beneath the occipito-frontalis and the orbicularis palpebrarum. It arises from the inner extremity of the superciliary ridge, its fibers passing outward, to be inserted into the under surface of the orbicularis palpebrarum opposite the middle of the orbital arch. There are decided variations, however, in this muscle, as in others of the group, and also in the distribution of the fascia near the center of the forehead.

These variations are appreciated when we compare the drawings given by Gray, Fig. 63, and by Henle, Fig. 64, and become very evident after even a few dissections.

The second group of fibers to be noted includes those of the *pyramidalis nasi*. These arise from the edge of the orbicularis, and with those on the opposite side pass downward covering the upper part of the nose. Usually this muscle is very imperfectly developed.

FIG. 63.—Muscles of the face and head (Gray).

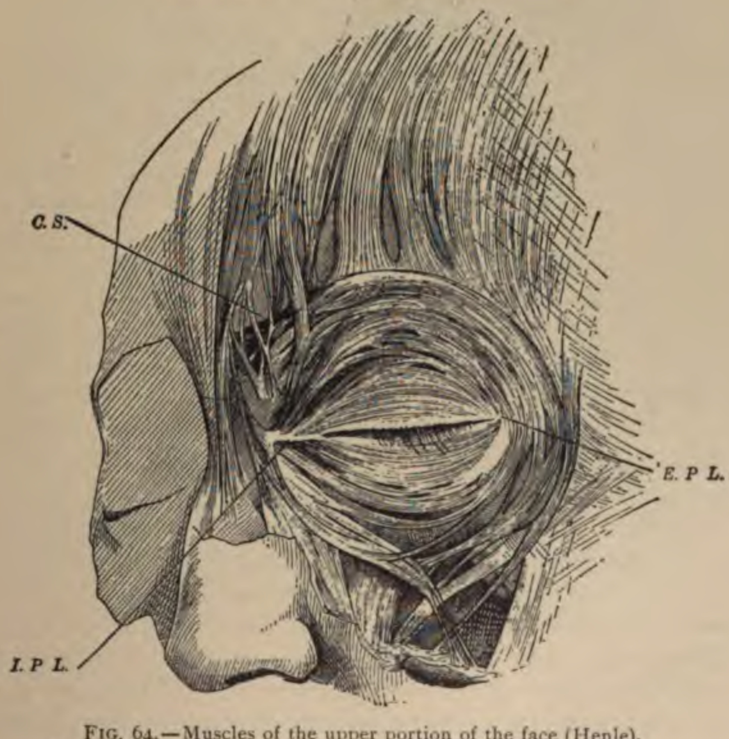

FIG. 64.—Muscles of the upper portion of the face (Henle).

The third and by far the most important accessory muscle of accommodation is the *occipito-frontalis*. According to Gray and Henle the occipital portion of this muscle arises from the outer half or two-thirds of the superior occipital ridge and from the mastoid portion of the temporal. The few fleshy fibers forming this portion soon become tendinous and pass upward as an aponeurosis which covers the whole posterior and upper portion of the skull. (Fig. 65.) As the anterior continuation of that aponeurosis, or skull-cap, we have the frontal fleshy portion of this muscle. It is quadrilateral in form, and as the fibers come forward a few pass downwards to blend with the fibers of the orbicularis, with the corrugator, and other muscles at the root of the nose.

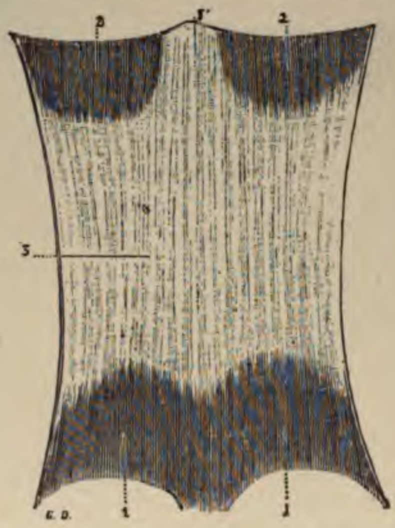

FIG. 65.—Schematic representation of the occipito-frontalis muscle (Testut). 1. Frontal portion. 2. Occipital portion. 3. Aponeurosis connecting these two portions.

The contraction of the anterior fibers of the occipito-frontalis causes, as we know, the well-known horizontal wrinkling of the forehead giving the expression of surprise, fear, etc., as has been shown by Darwin. In certain forms of muscle imbalance, especially when the vertical muscles are affected, the eyebrows are raised and these horizontal wrinkles become particularly prominent. Reference will be made to this later. The foregoing description, with more or less elaboration, we find in the classical works on anatomy. The origin and attachments of this muscle are, however, worthy of more exact study. Apparently there is no exact description of the connection between its posterior portion

and the trapezius muscle. It is not difficult, however, to see that these two muscles are quite intimately joined. For, in making dissections of the tissue over the superior curved line of the occipital bone, if the superficial fascia be first removed, it will be observed that the deeper fascia, which is quite adherent to the posterior portion of the occipito-frontalis, is also adherent to the trapezius. The outline drawing (Fig. 66) illustrates imperfectly the connection between these two muscles. As the fibers of the trapezius muscle curve downwards over the shoulders, it is evident that if in forcible accommodation the individual scowls and wrinkles the skin of the forehead, that tends to

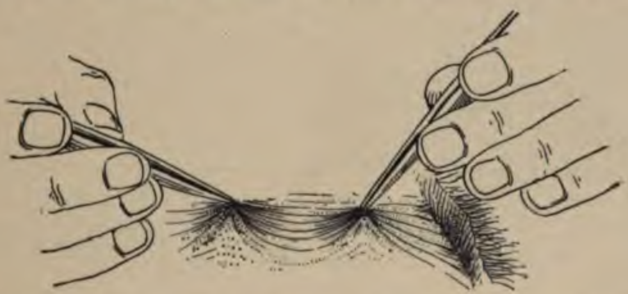

FIG. 66.—Diagram showing the manner in which the fibers of the occipito-frontalis continue into those of the trapezius. A part of each muscle is lifted by each pair of forceps.

draw also on the posterior fibers of the occipito-frontalis, and through them, the traction extends to the trapezius as has been already mentioned. Later, reference will be made to this fact in connection with headaches, pain in the occiput, or back of the neck.

Fourth. The *orbicularis palpebrarum*. This is not usually classed with the accessory muscles of accommodation, and yet, the more one studies the arrangement of its fibers, and also those contractions of the lids which come with excessive effort at accommodation, the more does it appear, from a clinical standpoint, to belong to this group.

A word should be added concerning it, not only for the reason above stated, but also because of its antagonistic action to the levator palpebræ. The description of it in

the different text-books varies as much as the muscle itself, and these differences are not slight, as will be found by any one who will take the trouble to make a few dissections. Most of the English text-books describe it as practically one sphincter muscle, the fibers of which pass around the palpebral fissure above and below from the palpebral ligament. This arrangement is simple and probably exists in some subjects. More extended descriptions of it are given by Henle, Merkel, and others. The special point of interest to the ophthalmologist is that this is not a single muscle, but practically is made up of three. The first part covers the lid itself above and below. The second part is almost a distinct oval concentric with the first, while the third tends to form another oval, just outside of the second, this last one being composed of irregular fibers more or less developed, which extend over the face (Henle) or upward to join the occipito-frontalis, blending with that muscle. Thus we have three muscles apparently with different actions. The first portion contracts in the act of winking. The second acts with the first in winking or in the frowning which accompanies accommodation. The fibers of the third group are only brought into action when a strong effort at accommodation is long continued, or, of course, when the lids are forcibly closed.

CHAPTER III.

THE NERVE SUPPLY OF THE MUSCLES.

§ 1. **General Considerations and Macroscopic Anatomy.**—The importance of this aspect of our subject is self-evident. Some writers even go so far as to say that all myology resolves itself into neurology, and while, in view of the anatomical differences in the muscles themselves and in their insertions, that statement is more epigrammatic than true, it nevertheless expresses a popular opinion.

It is possible to refer to the subject only briefly here, nor is it desirable to do more, as the macroscopic anatomy especially is known to every student, or can be referred to in familiar text-books. It is well in approaching this part of our study to recall the nomenclature, formerly so confusing, as Barker points out (B 193), but which has been modified of late years. We must remember that the brain which is under examination is supposed to be held relatively in position and immediately in front of the student. We can then understand how that which is posterior or spinalward is also proximal, while that which is cerebralward is also distalward. Transverse means on the horizontal plane. A frontal section is that which is at right angles to the long axis of the medulla. Median is the central vertical plane from before backward, while sagittal is also in a vertical plane from before backward, but not necessarily in *the* median line. Although these definitions may seem elementary, they are necessary in view of the too-prevalent confusion concerning them.

The nerves which supply the ocular muscles are the third, fourth, the ophthalmic branch of the fifth, and the sixth. When we turn to Gray, or any of the standard works on anatomy, we find these arranged in the order familiar to

every student. In reality, the parts as a rule are more distorted than usually represented, and more like the illustration given by Barker. (Fig. 67.) It is not easy to remove the brain so as to obtain a good view of all the nerves, for the reason that the fourth is so delicate and its origin so loosely attached that it is frequently torn away in

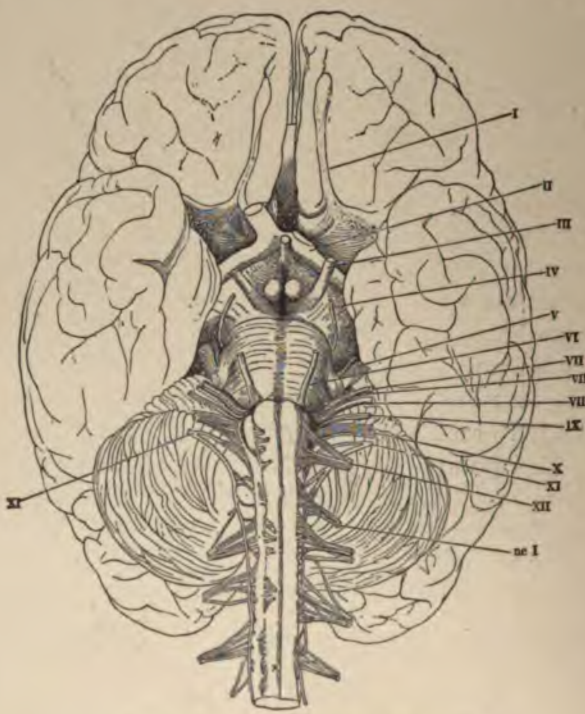

FIG. 67.—Base of the brain (Barker).

drawing the brain forward. When, however, a satisfactory specimen is obtained, we see that the four nerves which are of interest in this connection all leave the brain from the pons Varolii or immediately adjacent to it. This part, then, evidently requires close inspection.

Figure 68 gives as good a view, perhaps, as any, of the anterior surface of the pons with its relation to the medulla oblongata, while the posterior view (Fig. 69) shows the

fourth ventricle as it appears when its roof is parted in the middle, as if pushed to either side. Fig. 70 shows the arrangement of alternate transverse and longitudinal fibers as they appear in a section through the median plane. It must be remembered, however, that these

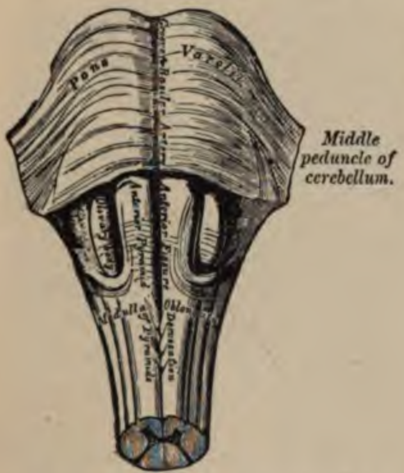

FIG. 68.—Medulla oblongata and pons, anterior view (Gray).

FIG. 69.—Medulla oblongata and pons, posterior view (Gray).

FIG. 70.—Median section of medulla oblongata and pons. Diagrammatic (Gray).

drawings are in some respects hardly more than rough diagrams. They indicate the direction of the fibers and

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give their names, but do not represent what the student of anatomy really sees. A better idea of a median section through this region is given by Figure 71. This shows the relative size and the position of the fourth ventricle, with the structures in that vicinity.

The view of the base of the skull (Fig. 72) shows the foramina through which the nerves make their exit.

FIG. 71.—Sagittal section through the pons. In making this, the aqueduct of Sylvius was opened at one small point, as shown by the dot nearly in the center of the figure between the third and fourth ventricles.

Having recalled these preliminary facts of macroscopical anatomy, and the general arrangement of the structures in the region of the fourth ventricle, we are better prepared to study the deep origin of the nerves which supply the ocular muscles. It is instructive also to glance at the grouping of the cells in the medulla and pons before studying the details of each group separately. Their arrangement is shown in the admirable diagram first given by Edinger (B 144) and reproduced here. (Fig. 73.) The most important structures in the pontine system lie almost immediately below the floor of the fourth ventricle. An idea of these can be

obtained by making a median section and then carefully dissecting off the thin layer of fibers which constitutes the floor of that ventricle. Unfortunately, this is by no means an easy task, as the interlacing of the fibers makes their

FIG. 72.—View of part of the base of the skull, showing the foramina through which the nerves make their exit (Bernheimer).

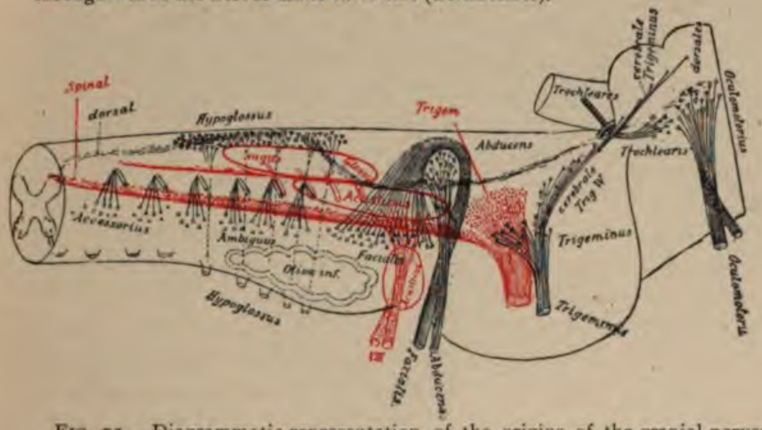


FIG. 73.—Diagrammatic representation of the origins of the cranial nerves in the pons and in the medulla (Edinger).

separation, especially at certain points, almost impossible. The best views of the arrangement are obtained by serial sections perpendicular to the axis of the pons and also in various vertical planes. It is from such dissections and thin sections, especially of the fœtus, that we learn the direction of the fibers in this important portion of the brain. A general view of this arrangement is seen in Fig. 74.

§ 2. **Third Nerve (Motor Oculi).**—The origin of this nerve presents three parts for examination. These are: (A) The nucleus itself. (B) A group of cells in the gyrus angularis. (C) Fibers which connect these two portions. Let us consider them in order.

(A) *The Nucleus in the Pons.*—Most of the fibers composing this important nerve arise from certain groups of cells which, together, we call the nucleus. This lies just beneath the aqueduct of Sylvius, near its posterior or proximal end, part of the nucleus lying on one side of the median plane and part on the other. If the entire nucleus were dissected out, it might be described as roughly egg shaped, five to six millimeters long from before backwards, and broader posteriorly than anteriorly. Closer inspection shows that it is made up of two equal irregular masses which are united in the median plane. Each part is slightly concave externally, having rather sharp converging edges internally and downward, and divergent smaller ends externally and upwards.

Let us consider next the microscopic structure of this nucleus and the arrangement of the different groups of cells of which it is composed. This arrangement is ascertained by the study of serial sections, the observations of various histologists being virtually in accord, no matter which method of staining is adopted. One of the most complete of these descriptions is given by Bernheimer (B 195). Copies are here shown of three frontal sections, but it is practically impossible to reproduce the different groups of cells exactly even with the contrast of different colors. Of these sections Fig. 75 is near the posterior end of the nucleus, Fig. 76 near the center, and Fig. 77 nearer the anterior end.

When we study these sections we find that all the cells arrange themselves into about five principal groups.

(a) On each side, near the lateral portion of the nucleus, is a considerable group which we will call a and a′. These are the so-called large lateral cells. It is probable that this group may itself be subdivided into smaller groups of cells, but some sections indicate that the groups merge into each other. The principal part of this group is made up of

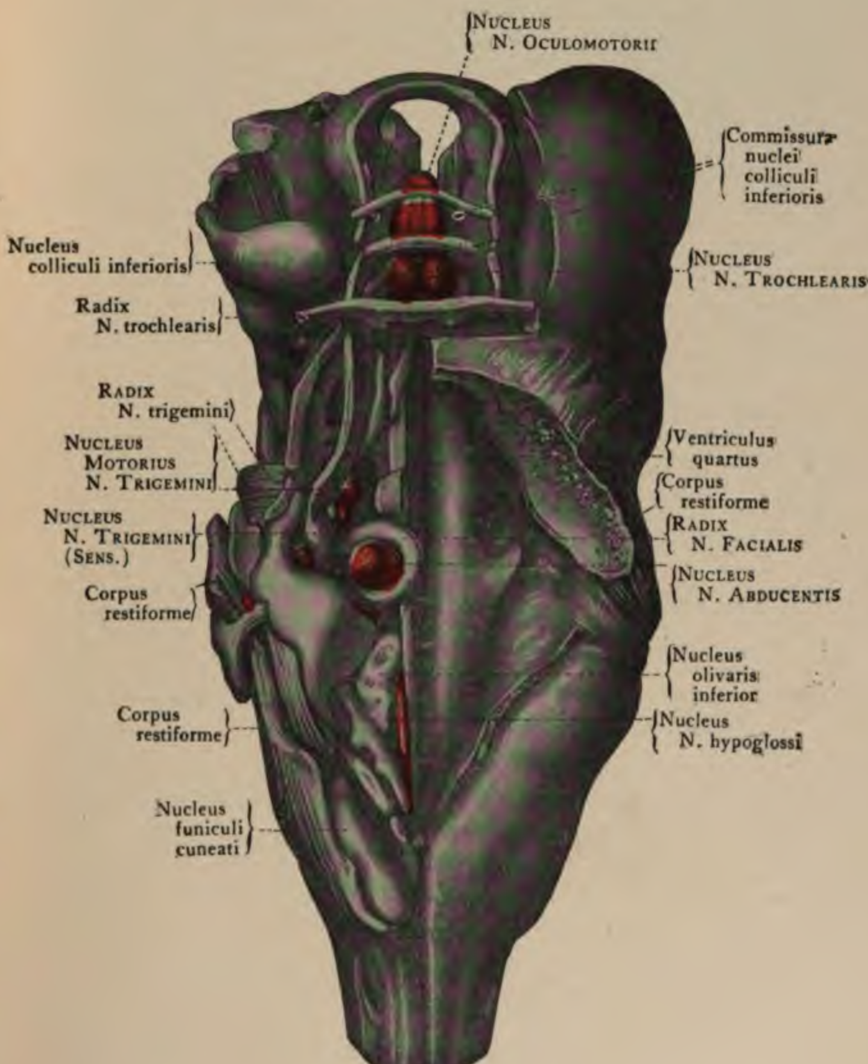


FIG. 74.—General view of the pontine system and of the structures lying beneath the floor of the fourth ventricle (Sabin's model of this part of the brain).

multipolar cells of considerable size, about forty micromillimeters in diameter, which, when properly stained, show a central granular nucleus. From these cells ultimate nerve fibers pass basalwards, joining with other fibers to form the nerve trunk on either side. Von Gudden (B 112) considers it certain that at least a partial crossing of the fibers from one side to the other does occur.

FIG. 75.— Frontal section near the posterior end of the nucleus of the motor oculi (Bernheimer).

(b) On each side, above and near the median line, is a small group of small cells (b and b′). As the upper end of each one of the main groups of large cells (a and a′) bends away from the median plane, it leaves a space which is occupied above by this so-called supplementary group. The cells which compose this group are perceptibly smaller than those in the main lateral group, and give to the stain a lighter color. This large group of large cells (a and a′), together with the small group of small cells (b and b′) situated on each side of the median line, constitute what may

FIG. 76.—The same near the central portion (Bernheimer).

FIG. 77.—The same near the anterior portion (Perlia).

be called the lateral portion of the nucleus of the third nerve. In addition to these there is yet another mass of cells.

(c) In the center, and below the two last mentioned, is a cluster of larger cells. It is made up of two halves, which coalesce to form a single small group lying in the median line. It is spindle form, directed up and forwards, only two or three millimeters in length, and is composed of cells of the same size, form, and color as those which, on each side, we already know as a and a'. Frontal sections show this spindle-shaped central mass to be bordered with a delicate network of nerve fibers. Briefly stated, these are the principal groups of cells which together form what is known as the nucleus of the third nerve, namely, the main lateral group (a and a'), the smaller group (b and b') on each side, and the central group in the median line (c). From these cells the fibers pass downwards and forwards, emerging, as is well known, just anterior to the pons near the median line.

(B) *Cells in the Cortex.*—The nucleus just described is not, however, the only group of cells sending motor fibers to the ocular muscles. We know at least one other point in the brain in which such cells are located, and there may be several. Ferrier noticed that irritation of a certain point of the cortex of the frontal lobe was followed by contractions of the ocular muscles, and his experiments, made on monkeys, have been verified by pathological conditions found in man. This point is just above the fissure of Sylvius, near its center, as shown in the annexed figure of the brain of a monkey. (Fig. 78.) This same portion is seen in Fig. 79. We have still much to learn concerning the general structure, arrangement of the cells, and distribution of the nerve fibers in this portion of the brain. In addition to the cells of origin (A) in the nucleus and (B) in the cortex, we have

(C) *The Fibers in the Brain which Connect these Two Points.*

There is no question as to the existence of some such fibers, but there is a sad lack of knowledge of their number

and direction and of other data concerning them. With the great advances made by Ramon y Cajal and others in

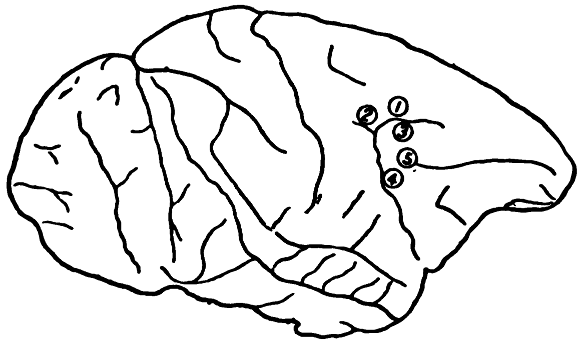


FIG. 78.—The external surface of the right half of the brain of *Macacus sinicus*. The numbers denote the chief points, the excitation of which evoked movements of the eyes. 1. Upward movement of both eyes. 2. Downward movement of both eyes. 3. Movement of both eyes upward and to the opposite side. 4. Movement of both eyes downward and to the opposite side. 5. Convergence. (Russell.)

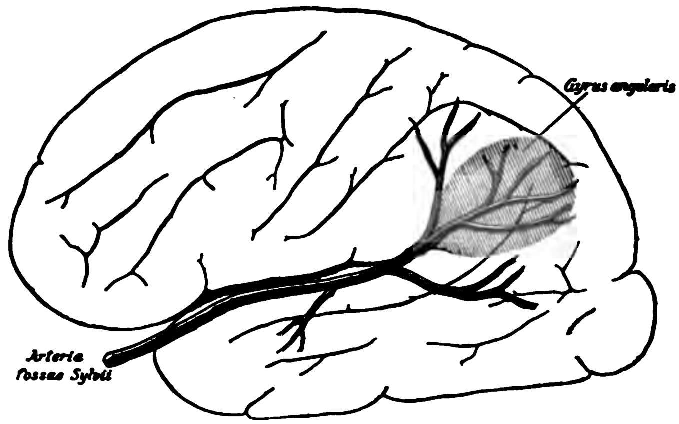


FIG. 79.—View of the gyrus angularis with its artery (Bernheimer).

methods of staining, this subject seems to furnish a fruitful field for those trained in microscopic technique.

It has seemed worth while thus to devote a little space to the deep origin of this nerve because of its own importance,

and also because so little concerning it is available to English readers.

After the motor oculi leaves the brain, it is not only easily followed, but is so well known that it is simply necessary to turn to any one of the standard works of anatomy or of ophthalmology to find there a detailed description of its course. We recall how it passes forward (Fig. 80), entering the orbit between the two heads of the external rectus muscle, then almost immediately separates into two divisions, one of which supplies the superior rectus and levator, while the inferior division passes to the internal rectus, and to the inferior rectus and inferior oblique. One set of the branches of this nerve is particularly interesting, namely, the long ciliary nerves, which pierce the sclerotic near the entrance of the optic nerve, passing along the choroid, to be distributed to the iris and the ciliary muscle. Their importance in connection with the act of accommodation is evident. Another set of branches of special interest are those in the very anterior part of the orbit, which anastomose with branches of the facialis. It is not impossible, as we shall see later, that upon this anastomosis depends the contraction of some of the accessory muscles of accommodation, with the frontal headache so often complained of. The general

FIG. 80.—Third, fourth, and fifth nerves in the orbit. (Gray.)

plan of distribution of the main branches of this nerve is shown in the accompanying diagram. (Fig. 81.)

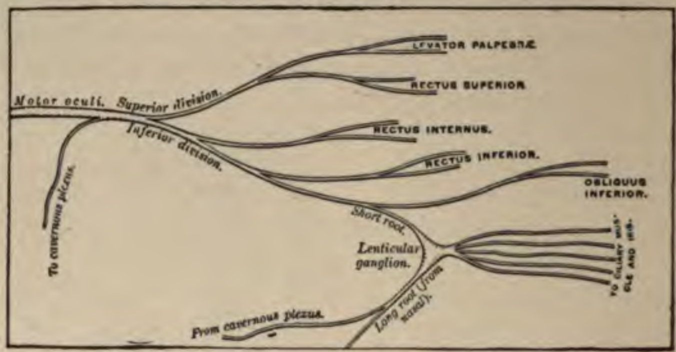


FIG. 81.—Plan of the motor oculi nerve (after Flower).

§ 3. **Relation of Certain Groups of Cells in the Nucleus of the Third Nerve to Certain Ocular Muscles.**—In this portion of our study, facts relating to physiology and pathology are excluded as much as possible, but it is best at this point to follow still one step farther, the relation between certain parts of the nucleus and the corresponding muscles, although in doing so we have to deal also with phases of physiology. Perhaps the most important evidence on this point is furnished by the experiments of Von Gudden (B 133). In very young animals he destroyed

FIG. 82.—Frontal section of the nucleus of the motor oculi of a rabbit. In this animal one of the third nerves was destroyed soon after birth. When the animal was grown it was killed, and this section made. It will be noticed that the nuclear cells on one side have disappeared (Von Gudden, Plate XXIX., Fig. 2).

separate muscles or whole groups of them, drawing out also, in some cases, the nerves which supply them; then, when the animals had attained maturity, he made sections of the nucleus, and with suitable stains ascertained in what part of the nucleus there had been a degeneration of the cells. Some of his findings were quite striking. (Fig. 82.)

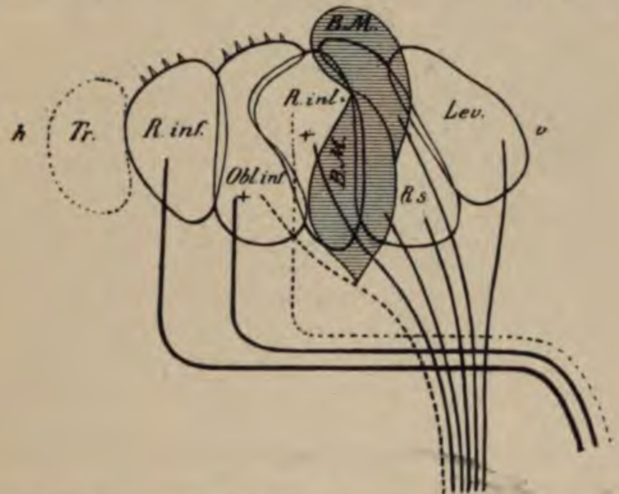


FIG. 83.—Schematic sagittal section through the nucleus of the third nerve (Bernheimer). *v*, anterior. *h*, posterior portion. The subdivisions of the nucleus represent the grouping of the cells not anatomically, but as they have been determined by experiment, with more or less exactness, to preside over the action of certain muscles. Thus the cells in the anterior group control the levator palpebræ; in the next group, the rectus superior; then the rectus internus, the inferior oblique, and the rectus inferior. *B. M.* indicates the location of cells which preside over the sphincter pupillæ, and therefore probably over accommodation. The heavy black lines from these cells indicate that the fibers go only to the muscle which is shown by the lettering. The lighter lines, and those which are dotted, indicate that the fibers go to that muscle and to others also.

The cells included on the dotted space posteriorly (*Tr.*) are not a portion of the nucleus of the third nerve. This is the nucleus of the trochlearis.

The functions of the various groups and subdivisions of groups of cells which constitute the nucleus of the third nerve have been investigated by different observers (B 131, 133, 136, 161, 165, 174, etc.) and the conclusions arrived at accord in the main so well, that Bernheimer, who is

probably our best authority on this point, has constructed the accompanying diagrams to show which portions of the cells or group of cells preside over the action of the different ocular muscles. (Figs. 83 and 84.) In these diagrams the central portion, which is shaded, corresponds roughly to that group of cells which in the microscopic sections we have called (c). The group of cells superiorly which are also shaded are those which in the sections we have called b and b′. The cells and parts of the groups which are not shaded are those which correspond in the frontal sections to those groups of cells which we have called a and a′. The summary of our knowledge of the function of these different groups and subdivisions of groups may be stated about as follows.

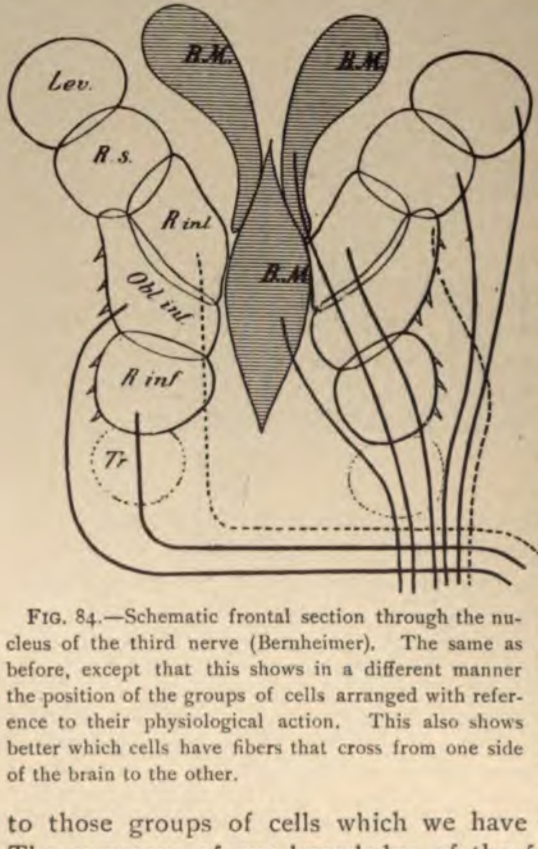


FIG. 84.—Schematic frontal section through the nucleus of the third nerve (Bernheimer). The same as before, except that this shows in a different manner the position of the groups of cells arranged with reference to their physiological action. This also shows better which cells have fibers that cross from one side of the brain to the other.

First. The group of cells (c) which lies in the median line of the sections gives off fibers which supply the ciliary muscles, causing contraction of the pupil and assisting in accommodation, if not presiding over it.

Second. The group of cells lying on either side of this band also presides over the contraction of the pupil. It is

not certain whether each of the fibers of these two groups passes to the corresponding side of the body or whether they are crossed.

Third. The group of cells which form, on either side, the principal mass of the nucleus (a and a′ of the microscopic sections or the parts in outline of the diagram) supplies, as a whole, the fibers going to the extraocular muscles.

These three points are established with a very considerable degree of certainty. But when we attempt to go beyond that, we deal with probabilities rather than with convincing proof. With this understanding, we may take up the different portions of these lateral groups of cells.

Fourth. The posterior point—that point which is almost in contact with the nucleus of the trochlearis—innervates the inferior rectus muscle of the opposite side.

Fifth. The cells just anterior to these innervate the inferior oblique of the opposite side.

Sixth. The cells next to these innervate the rectus internus.

Seventh. The most anterior groups innervate the superior rectus and the levator, although this and the preceding statement are hardly more than inferences by exclusion.

Such is a general outline of the functions of these different groups of cells as given by Bernheimer and others.

While making this digression from the strictly anatomical question in order to inquire into the functions of these groups of cells, we may include the clinical evidence bearing on this point. Such evidence rests upon the principle that if two or more branches of the nerve (*i. e.*, muscles) are paralyzed, and especially if these two or more are affected in the same or in a similar manner, in different individuals, then it is probable that the cells of origin of these branches lie near each other. If the number of such cases were quite large, it would thus be possible to construct a diagram showing the position of the different groups of the cells with regard to each other, as indicated by these partial paralyses. Such a plan has been elaborated by several investigators, especially by M. Allen Starr (B 126) of New

York. (Fig. 85.) For this purpose he collected twenty cases of partial paralysis of the third nerve, and arranged them in order with reference to the "relative position of the nuclei and the extent and degree of paralysis in each case cited," the numbers in his diagram corresponding to the different cases cited in his list. These are underlined when the paralysis of that muscle was complete. It is interesting to know that the results obtained in this way clinically correspond fairly well with results obtained by experiments. If our cases of partial paralysis of the third nerve were reported more frequently, we should have much more abundant data, from which conclusions of value might be drawn. Here the clinician can aid the physiologist.

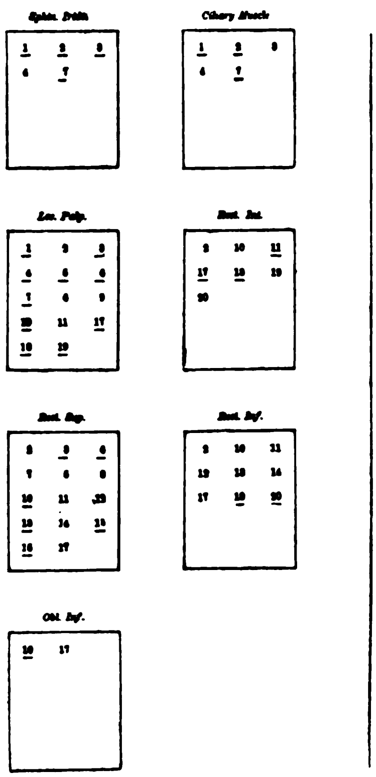


FIG. 85.—Diagram by M. Allen Starr of cases of partial paralysis of the third nerve. The branches which have been affected are placed next to each other, and for convenience they are arranged as if all were on the left side. The numbers are simply to identify certain cases of a series of twenty, which were brought together by Starr.

The student who approaches this subject for the first time may wonder why so much attention is given to the relation between certain groups of cells in the nucleus and certain ocular muscles, but the reason will be evident enough when the various forms of paralysis are considered.

A final question, partly anatomical, partly physiological,

concerning the third nerve, is its connection with the occipito-frontalis, the corrugator supercilii, or other accessory muscles of accommodation, for in the chapters on muscle imbalance we shall see that some of the muscles controlled by the third nerve, especially the internal recti and the sphincter of the iris, bear an important relation to these accessory muscles. Apparently no branch of the third nerve has been traced to those muscles, nor is there any anastomosis which explains entirely the physiological and pathological phenomena with which we are familiar. It should be remembered, however, that the terminal filaments, and especially the anastomosing branches of the nerves, are often microscopic and very readily mistaken for connective tissue fibers. No one appreciates this until he has worked patiently for a long while to follow a single fiber only a short distance. The fact that we can not readily see such an anastomosis, therefore, does not prove that it does not exist. The intimate relation between the internal rectus when acting with the ciliary muscle and the accessory muscles of accommodation will be referred to in the chapter on physiology, and in the part relating to asthenopia.

Corroborative evidence of the connection between these groups of muscles is shown by those occasional cases of "total ophthalmoplegia in which the occipito-frontalis and orbicularis palpebrarum are affected, whilst the lower facial muscles escape." (B 230.)

One of the most important observations concerning the nerve supply of the muscles of the face has been made by Mendel (B 226) of Berlin. His plan of study was similar in principle to that adopted by Von Gudden, and the conclusions, briefly summed up, are that "the frontal and orbicularis muscles, although peripherally supplied by the facial nerve, are 'eye muscles' and form the 'oculo-facial' group whose central innervation is the oculo-motor nucleus." This gives us an anatomical basis for that intimate relation which we find physiologically and clinically between efforts at contraction of the ciliary muscles and of the accessory muscles of accommodation. We shall see later that the prolonged and forcible contraction of these accessory

muscles causes at least a part of the headache and discomfort which is such a prominent symptom in eye strain.

§ 4. **Fourth Nerve (the Trocnlearis).**—The deep origin of this nerve is better known than that of the third, and its structure is less complicated. It consists of a single group of cells on each side of the brain which lie posteriorly and spinalward from the cells which make up the nucleus of the third nerve. The nucleus of the fourth is much smaller than that of the third, its diameter being only three or four millimeters, or large enough to furnish about forty moderately thick sections. It is roughly hemispherical, the convex surface being directed downward and backward. When the fibers leave this nucleus they pursue a very tortuous and

FIG. 86.—The anastomoses of the fourth nerve (Cl. Bernard).

unusual course. Starting at first in a horizontal direction backward, they turn upward in front of the motor root of the trigeminus, then inwards and above the aqueduct of Sylvius. Emerging from the brain substance, the nerve crosses to the opposite side, and curves forward and outward. Then, being in contact with the outer side of the crus, it reaches the base of the brain. From that point forward its course, like that of the other cranial nerves, is easy to follow. It passes along the edge of the tentorium, just above the opening where the fifth nerve makes its exit from the skull, and enters the orbit through the sphenoidal fissure near both the third and the fifth nerves. Thence it turns inwards, and is distributed to the fibers of the superior oblique. The anastomoses of the fourth nerve are shown in the accompanying diagram from Claude Bernard. (Fig. 86.)

§ 5. **Fifth Nerve (the Trigeminus).**—The cells at the origin of the two roots of this nerve are arranged principally in a long row which extends on each side of the median line of the medulla. (Fig. 73.) Commencing above, on either side, in the substance of the corpora quadrigemina, they stretch downward and backward for some three centimeters or more. Opposite the center of the pons the cells are especially abundant, and the fibers passing basalwards have the appearance, when taken together, of a short, thick camel's-hair brush, with the point held upwards. From this group of cells, or principal nucleus of the fifth, as it may be called, another long band of cells stretches off spinalwards at the side of the median line. As the nerve fibers from each cell pass first to the principal nucleus, to join with the other fibers, this extension backward of the cells with their fibers looks like a single line. The cells which belong to the sensitive fibers are small and round like those of the sensitive roots in the spinal cord. These cells form most of the principal nucleus, and of the row which stretches from that point spinalward.

The cells which belong to the motor root are large and multipolar. They form only a small part of the principal nucleus, and extend from that point cerebralwards to the corpora quadrigemina, as already stated. The fibers of this group of cells also are directed first toward the principal nucleus and from that point all of the parts of the motor root join to emerge near the middle of the pons on each side of the median line.

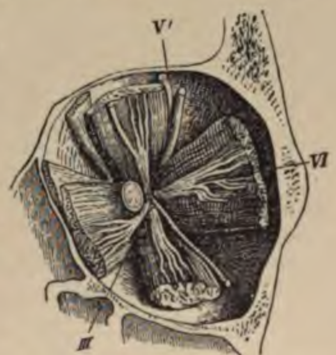


FIG. 87.—Frontal section of the orbit with recti muscles showing the entrance into the orbit of the third, fourth, and fifth nerves (Merkel).

As the sensitive and motor roots thus leave the brain together, the former soon enlarges into the well-known Gasserian or semilunar ganglion, and then separates into its three portions,—the ophthalmic, the superior, and the

inferior maxillary branches. The first of these, passing through the sphenoidal fissure (Fig. 87), divides into the lacrymal, frontal, and nasal nerves, as figured in most text-

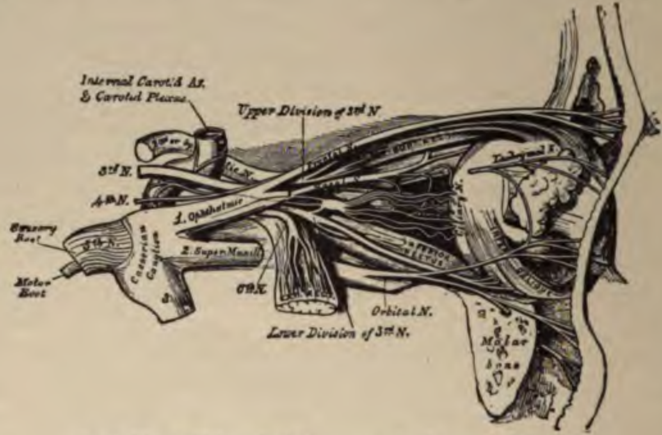


FIG. 88.—Fifth and sixth nerves in the orbit (Gray).

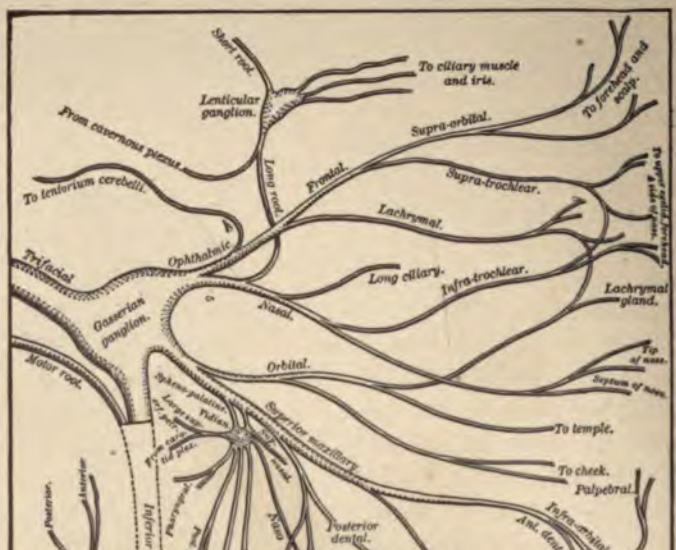


FIG. 89.—Plan of part of the fifth nerve (Flower).

books and as seen in Fig. 88. The fact, however, which is probably of the most importance in this connection is that the terminal fibers of the two latter subdivisions, as they spread out upon the forehead, supply the corrugator supercilii, the occipito-frontalis, and other muscles in this vicinity, —that is, the accessory muscles of accommodation. (Fig. 89.) The bearing of this fact will be seen when we consider questions relating to ocular headaches. We should also note that anastomoses occur between the smaller branches of the ophthalmic and the superior maxillary nerves, as this may account for pain in and about the eyes sometimes associated with dental caries.

§ 6. **Sixth Nerve (the Abducens).**—The group of multipolar ganglion cells which constitute the deep origin of this nerve is situated just beneath the floor of the fourth ventricle, almost exactly in its center from before backward and two or three millimeters from the median line. They may be aptly compared, like the principal group of the nucleus of the fifth, to the tip end of a brush, two or three millimeters in diameter. (Figs. 90 and 91.) From this point the fibers pass straight downward and outward toward their point of exit from the brain. At first a few fibers joined to each other form separate bands, but these unite before they emerge from the brain.

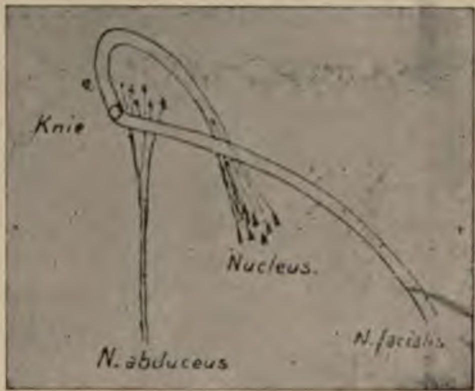


FIG. 90.—Relation of the nuclei near the origin of the sixth and seventh nerves (Mauthner).

It is interesting to observe the curious relation of the seventh nerve to the sixth, near their points of origin (Fig. 90).

The sixth, as just mentioned, commences in a brush-

shaped extremity and passes straight down and outward to its destination. The nucleus of the seventh is at first below, spinalwards and laterally from that of the sixth. From that point the fibers start first dorsal and cerebralward and, curving almost in a loop around the nucleus of the sixth, retrace their course and pass downwards and outwards in a direction similar to that of the sixth nerve. Indeed, in the latter part of their course in the brain the sixth and seventh lie very nearly in the same frontal plane (Fig. 91), the latter

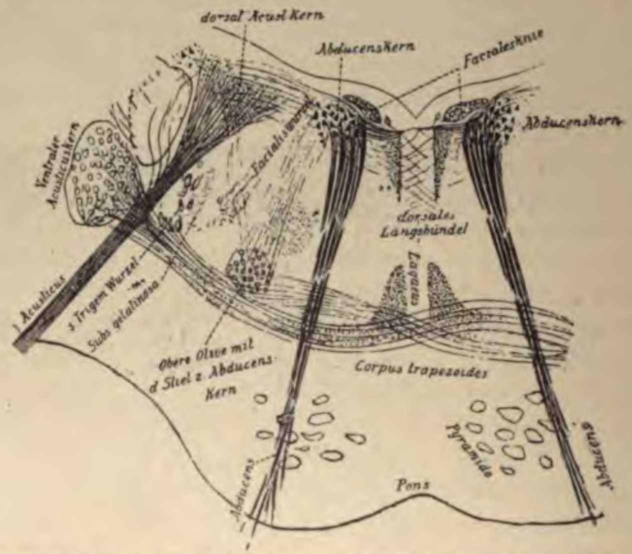


FIG. 91.—Frontal section through the origin of abducens nerve (Edinger).

nerve emerging somewhat farther than the sixth from the median line. Neither the sixth nor the seventh crosses from one side of the brain to the other.

On emerging from the brain, the sixth nerve passes along the groove on one side of the sphenoid bone, enters the orbit between the two heads of the external rectus muscle, and at once divides into small filaments which are distributed to the fibers of that muscle.

§ 7. **Branches of the Sympathetic.**—Any description of the nerve supply to the ocular muscles would be incomplete without some mention of the innervation through the

sympathetic. These branches come, as we know, from the ophthalmic ganglion. This is usually described as a flattened lenticular bit of reddish gray matter, two or three millimeters long, lying at the back part of the orbit just external to the optic nerve (Fig. 88). Some descriptions give it three afferent branches, and others describe only two. The longer or superior branch is well marked, and comes from the nasal branch of the ophthalmic nerve. A filament also comes from the cavernous plexus and this is sometimes joined by another afferent branch, which comes from the twig going to the inferior oblique. The branches of distribution from the ophthalmic ganglion vary in number from three to half a dozen. All of these pierce the sclerotic not far from the entrance of the optic nerve, and pass forward ultimately to the ciliary process and to the iris.

Only one who has attempted to make a dissection of this ganglion can appreciate why the descriptions given of it vary so decidedly. Even when one knows exactly where the ganglion lies it is difficult to find it, and after it is found, it is almost impossible to decide whether the hair-like filaments which lead to and from it are really nerves or only fine threads of connective tissue. In any case they are very apt to be torn before the dissection is completed. The ganglion is rarely seen in anatomical collections, although a very beautiful dissection was shown me some years ago by Axenfeld of Freiburg.

As mention has been made of the functions of the cells in the nucleus of the third nerve, so in passing we should make note here of the action of the branches of the sympathetic. It is generally supposed that they control the action of the dilator pupillæ. While this is one of their functions it is probably not the only one. Indeed, the study of the anatomy and physiology of the ophthalmic ganglion — to say nothing of its pathology — is a subject which has been too much overlooked, and judging from the paucity of literature on that subject it is an excellent one for investigation.

CHAPTER IV.

THE BLOOD-VESSELS.

THE blood-vessels which supply the muscles are not of sufficient importance to warrant more than passing notice. The accompanying illustration (Fig. 92) shows that as the ophthalmic artery enters the orbit, it divides into various branches, some going to the muscles and some to the globe. It is worth while to recall a point concerning the arteries distributed to the ciliary muscle. Of its three sources of supply, one is the anterior short arteries. These consist of minute branches from the recti, near their insertion, and from that vicinity. They pass over the globe, perforating it at a short distance from the margin of the cornea. This apparently accounts for the fact that any change in the blood supply to the extraocular muscles may influence that of the intraocular muscles also.

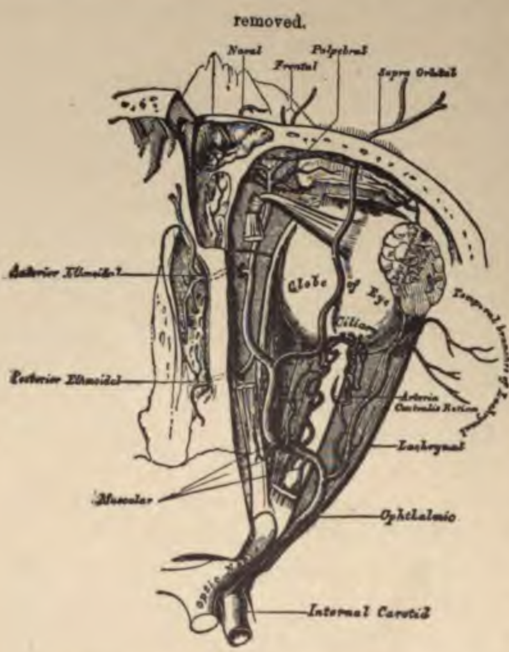


FIG. 92.—Blood supply of the muscles (Gray).

There is one small artery, though, of special interest to the student of the muscles. That branch, however, is not near the muscles, but in the brain. It is the arteria fossæ Sylvii with the accompanying vein. (Fig. 79.) After this artery passes upward and backward along the fossa of Sylvius it divides usually into three branches. One of these passes down and backwards, another almost directly upwards, while the central branch, which in most brains is practically a continuation of the original artery, extends backwards to supply the gyrus angularis. It is in this immediate vicinity, as we have already seen, that the cortical cells are situated which also control the movements of the muscles. In the part of this study which relates to pathological conditions we shall find that certain forms of paralyses are so sudden in their onset as to indicate beyond doubt that they are due to an effusion of blood. Such a history, together with other clinical evidence, as well as post-mortem conditions, shows that in a considerable proportion of these cases the hemorrhage is not in the vicinity of the nucleus of the third nerve, but in the region of the gyrus angularis—in other words, from some branch of this arteria fossæ Sylvii.

CHAPTER V.

COMPARATIVE ANATOMY AND EMBRYOLOGY OF THE OCULAR MUSCLES.

§ 1. **Ocular Muscles of the Lower Vertebrates.**—A glance at the eye muscles of the lower vertebrates shows that their general arrangement is similar to that which exists in the human orbit, except that we often find in addition, especially among the mammals, a strong muscle known as the retractor or choanoid muscle. A great difference in the details of their arrangement, however, exists among the different orders and genera. At the outset we should remember that as the position of the animal's head is usually horizontal, the terms indicating direction—up and down, in and out—have a different meaning than when used with reference to human anatomy. Thus "posterior" indicates the direction from the anterior to the posterior portion of the animal, although in some instances when the head inclines downward this means really from below upward. Also, the term "inwards" means toward the median line, although in some cases this becomes upward; outwards is of course in the opposite direction.

Dissection.—In dissecting the ocular muscles of the fishes and even some of the mammals it is better to disarticulate the lower jaw and open the orbit from the roof of the mouth. In this way the best view is usually obtained, especially in the fishes, as with them the ocular muscles extend from the sphenoidal canal. With the higher mammals like oxen, hogs, dogs, etc., it is better to remove the skullcap and approach through the orbit from above, as in dissecting the human eye.

The literature of the comparative anatomy of the ocular muscles is not extensive. An excellent descrip-

tion was given of the muscles of the cat by Mivart in 1881, and in the monograph by Motais (B 17) already referred to the subject is treated at considerable length. He has made beautiful dissections of the eye muscles of different animals, and I have been able to verify the descriptions as regards several of the common fishes, the domesticated birds — such as thec hicken and turkey,— and the larger domesticated animals, including the pig, horse, sheep, and ox.

Fishes.—Among the fishes of the lower types or the Chondropterygiens (those having cartilaginous coverings) we find, instead of six muscles, that the recti are bifurcated or subdivided into smaller bands, so as to give the appearance of a larger number of muscles—as, for example, is shown in the sunfish (*Orgathoriscida mola*). This, perhaps, is a remnant of the still earlier forms of life in which the eye is moved either by one cone of muscles, or by many small filaments attached to different parts of the globe. Even in this class of the lower fishes we find in some instances that the globe is turned by four well-marked recti muscles and two obliques, although there are individual differences in this respect.

Passing to the fishes with bony skeleton, or the Teleosteins, we find still more frequently the type of the four recti muscles with the two obliques, the recti usually passing outwards and forwards from the optic foramen. The superior and the inferior oblique, however, spring from the more anterior portion of the skull just above the roof of the mouth, near its front portion, and then pass backward. Occasionally, among these fishes—as, for example, in the mackerel, and, to some degree, in the ordinary whitefish (*Coregonus albus*)—there is an ingenious contrivance for increasing the length and therefore the action of the recti muscles. Careful dissection shows that a small canal — the sphenoidal —extends from the orbit directly backward near the median line just above the roof of the mouth. This canal is practically an extension of the orbit almost at right angles to its principal axis. The recti muscles arise either from the extreme end of this canal or along its side, and then, passing

forward into the orbit proper, they turn outward at a more or less sharp angle to be inserted into the globe. This arrangement, of course, adds much to the efficiency of the muscles.

Amphibians and Reptiles.—Here, again, we find the same tendency to division into four recti and two obliques, and in addition there appears in some a more or less marked retractor muscle of the globe. This arises immediately behind the globe, and, passing outward, is attached into the sclerotic near the optic nerve. It is almost pyramidal in shape, the apex being situated at the origin of the muscles, with the base resting on the globe, between the insertions of the recti muscles and the optic nerve.

In a word, among these animals also, although the number and position of the eye muscles differ greatly, there is the same general arrangement as in the orbit of the fishes, except that there is seldom an extension of the recti into the sphenoidal canal. A curious muscular arrangement is met with, which, though not belonging strictly to the motor muscles, is worthy of mention, as it occurs also in many of the higher types, especially among the birds, cats, etc. This is the tensor membrana nictitans. Among the reptiles, this muscle is contained in a rather long tube situated at the outer or posterior angle of the eye and is attached by a minute ligament to the third lid. A contraction of this muscle causes this third lid to sweep entirely across the globe.

Birds.—Here is again the same general plan of six muscles for the movement of the globe, although there are often two others for the third lid. The plan of the origin and insertion of the recti and of the obliques is also in general the one with which we are familiar. Among the birds the retractor bulbi is seldom found. A very ingenious and curious arrangement, described more than a hundred years ago by Petit, Hunter, and others, ensures the rapid movement of the third lid.

With the birds this third lid has its origin, as usual, near the inner canthus, being somewhat quadrilateral in shape. To its outer and upper edges a fine tendinous filament is

attached, which passes up and outward around the equator of the eye, then behind the globe, and winding around backwards and downwards around the optic nerve, it terminates in a muscular band behind the globe. Moreover, in its course around the optic nerve it is drawn away from it by still another muscular band, through a loop which holds it in place. (B 244, vol. ii., p. 143.) In this way very much is added to the power of the muscle, with corresponding economy of space.

Mammals.—It is natural to expect that in this class the resemblance of the orbit and the ocular muscles to those of the human species would be closer and more constant than in any other class. That, however, is not always the case. A glance at the skeletons of the whales, which are so common in museums, shows that part of the walls of the orbit is entirely lacking. We find, too, that the orbits of the rodents are small, and in several other families the orbital walls are so arranged as to restrict necessarily the free action of ocular muscles. In general, though, these muscles are arranged on the same plan as in man and the lower animals, namely, four recti and two obliques, while many possess also the choanoid or the retractor bulbi.

It is unnecessary for our present purpose to go into details concerning the arrangement of the ocular muscles in the different orders of the mammals. As to the recti, it is worth while to observe that inasmuch as they do not usually spring from around the optic nerve, as in the human subject, but rather from one side of the orbit, the axis of the cone of these muscles is therefore at an angle more or less acute to the axis of the globe.

The retractor muscle is found in some of the highest and also most of the lowest groups of the mammals. The eyes of the hog and of the horse furnish very well-marked and familiar examples. In certain varieties, the muscle which moves the third lid is a prominent and important portion of the ocular anatomy, and the possible relation of this to the muscle of Horner has already been noted.

A word may be added concerning the action of the ocular muscles in the lower animals; the function of the recti and

of the obliques is of course the same as in man; the retractor bulbi moves the globe also in different directions, as do the recti, but to a limited extent. The function of this muscle, though, is pre-eminently the protection of the globe by drawing it farther within the orbit. This can be easily seen in the horse by tapping on the closed lid.

On one occasion when making an experimental operation on the eye of a horse, after the chloroform had been administered to a point which was considered sufficient, a suitable speculum was introduced between the lids. On attempting to fix the globe, however, the horse drew the globe so far into the socket as to make the operation impossible; in fact, only a small part of the cornea remained visible. But when more chloroform was administered and the retractor bulbi consequently relaxed, the globe came forward to its usual position.

It would be interesting to know whether an analogue of the retractor bulbi exists even occasionally in the human subject in the form of a supernumerary muscle. I have never happened to see any trace of this when making dissections of the orbit, nor is it mentioned by Bochdalek. It is certain, however, that in rare instances individuals are able to retract the globe within the orbit, and cases of voluntary retraction reported by Axenfeld suggest that these persons either have certain fibers similar to the retractor bulbi of the lower animals, or else that the recti muscles act in a very unusual manner to produce that result.

§ 2. **Embryology.**—As our knowledge of embryology increases we find constantly a larger number of facts which explain our clinical experiences. Therefore, aside from any general scientific interest which the subject may have, it is well to glance at a few points connected with the fœtal development of the ocular muscles. It is only possible to give here an outline of what is found in detail in the admirable articles of Ryder (B 248) and others. Frequently when studying this subject it is convenient to make use of the pig, and as such observations can be readily verified, this general description refers particularly to that animal. When the

embryo is about twenty days old it measures some ten millimeters in length, the head or anterior portion being about four millimeters long. It is much bent on itself, and has a slightly spiral form. The lower portion of the head is then hardly distinguishable, but already the vesicle of the eye has begun to form, and behind it there is a nucleus from which the muscles develop. About that time the first trace of the third and sixth nerves appears, but the fourth cannot then be discovered (B 246).

When the embryo has reached fifteen or twenty millimeters in length the development of the ocular muscles has increased even more rapidly. By that time the superior oblique and superior rectus are well defined, being quite closely joined together. The inferior rectus and inferior oblique are also distinguishable, lying near to each other. The external rectus is represented by a small projecting point, while the internal is not apparent in these sections. The third nerve, however, by that time is well marked.

Still later, when the embryo has grown to be about half as large again, the extraocular muscles are well defined and easily found by dissection. Their relative position also is almost the same as that which they occupy in adult life; in other words, these external muscles are all formed at quite an early stage. For it should be understood that at this stage the eye itself is far from complete. The lens is still in contact with the cornea, the iris has not yet appeared as a distinct structure, there is no anterior chamber, and no true cornea. The lids at that time are represented only by rudimentary folds of skin above and below the globe. Marshall (B 247, page 296) calls special attention to the fact that the external rectus has "nothing whatever to do with the first head cavity, though it ultimately reaches the eyeball." He further says: "This is a point whose importance can hardly be overrated, as it furnishes us with an explanation of the fact that the rectus externus is supplied, not by the third nerve, but by a totally distinct nerve—the sixth." Of the four muscles which are supplied by the third, three of them, and the fourth possibly, are developed from the walls of the first head cavity.

The subsequent history of the muscles of the embryo leaves but little to describe. From the stage last referred to, until birth, the development consists principally in an increase of the muscle tissue, the arrangement and relative size of the muscles remaining unchanged.

No consideration of the development of the muscles of the eye, however cursory, would be complete without having attention directed to the development of the nerves which supply these muscles. The third nerve, as we have mentioned, appears at a very early stage, but it soon divides into a dorsal and a ventral branch, as Corning (B 246) pointed out. An important point in connection with this nerve, and perhaps one of the most important facts in the embryology of the eye, is that the fœtal third nerve supplies not only the four eye muscles, but also, in certain forms, the branches of this nerve, extending outward, supply part of the tissues which later become accessory muscles of accommodation. This gives us another clue to the important relation between the muscles in the orbit and those which have been called by Mendel (B 226) the "oculo-facial" group. The fourth nerve is developed quite independently of the third. It begins apparently as a portion of the ganglion of the fifth nerve, but the intermediate stages of its development are as yet not clearly understood. The sixth, like the motor oculi, must be considered as coming from the ventral surface, or at least it has what we call a ventral root. In a word, we have the third nerve with the muscles to which it is distributed coming from one group of cells, the sixth nerve with the muscle to which it is distributed coming from quite another group of cells, while the fourth nerve is at first apparently a part of the fifth, but later quite independent of it, and goes to a muscle which is most nearly related to the group supplied by the third nerve.

PART II.

PHYSIOLOGY.

CHAPTER I.

ONE EYE AT REST.

§ 1. **Introduction to the Physiology of the Muscles.**— The "practical ophthalmologist" may perhaps think it quite unnecessary to review the physiology of the muscles, for the reason that this phase of the subject has been thoroughly worked out already. In the main that is quite true, and the files of *Graefe's Archives* and other journals of that class show what careful studies have been made of the normal ocular movements. But it is also true that many of the facts there recorded have no practical significance which can be seen in the light of our present knowledge. It seems proper therefore to select from this mass of observations those which are apparently of clinical importance, and arrange them, if possible, in such a manner as to form a systematic basis for clinical work. Moreover, it is better thus to bring the physiological data together than to scatter them through chapters where they would necessarily be confused with what relates to pathology.

When dealing with these questions we are obliged to turn almost constantly to those Continental authorities, especially the Teutons, who laid the foundations of our science with mathematical exactness. But when we come to the clinical conclusions resting on those foundations we shall have more to do with the applications of Anglo-Saxon ingenuity. If one may venture to follow the example of Tyndall and compare the subject of our study to a

geometrical figure, our knowledge of the ocular muscles could be represented graphically by a pyramid. It might be said that the one constructed by the earlier physiologists and mathematicians had a broad base, but did not reach far upward toward practical conclusions. On the other hand, in much that is written to-day, the effort to attain the practical end immediately, makes the pyramid too high for its base. Sometimes, indeed, the pyramid seems inverted. The problem is, therefore, how to make the structure strong and of goodly proportions.

Our first step must be to agree upon definitions, and for this purpose to view the eye as a globe at rest, examine its different planes, axes, and the angles which they form with each other, as reference must be made to these almost constantly. Then it is advisable to study the action of the ciliary muscle and how accommodation is affected by cycloplegics or myotics. The special reason for following this order, is that as soon as we approach any of the questions which relate to muscle imbalance, we must deal first of all with the ciliary muscle by seeking to bring it into normal relation to the extraocular muscles. After deciding what we are to understand by "accommodation," we can study the ocular motions. The movements of the globe are somewhat complicated, it is true, but the difficulty in understanding them will be greatly lessened if, beginning with one eye only, we observe first the simplest motion which it can make,—in and out, up and down,—and the limits of these motions. A further study of the lateral motions will lead us to consider the amount of force which the muscles can exert in making them, the time necessary to accomplish this and how to measure it, both when the globe swings uninterruptedly through an arc of a certain length, or when it goes halting, as in the act of reading. All these motions are comparatively simple and *can* be made by the rotation of the globe about an axis, either horizontal or vertical. After understanding these, we will be better prepared to consider other rotations, and the laws which govern them, especially those relating to convergence and torsion

Indeed, it may be stated at the outset, that the object of the physiological part of this study is not simply to review facts already known, or perhaps to add a few which are new, but it is rather to proceed in such a manner that we may be gradually led to a conclusion which has a most important significance. This is, that FOR COMFORTABLE BINOCULAR VISION, ESPECIALLY AT THE WORKING DISTANCE, A RELATION WITHIN CERTAIN LIMITS MUST BE MAINTAINED BETWEEN ACCOMMODATION, CONVERGENCE, AND TORSION. That proposition might be conceded without discussion. But to appreciate its importance, especially in all that relates to pathological conditions, it is necessary to go over the ground carefully step by step. It should be said also that the line of study will not always be easy. Possibly a little mental gymnastics may be required occasionally, and although we shall follow the beaten path whenever possible, because it is always the safer and easier, we must sometimes pick our way along where the footprints of other students are few and indistinct. Short digressions will also occasionally be necessary, in order that, as we proceed, we may gather physiological facts which are near at hand without being obliged later to retrace our steps. The value of these facts, although not always evident at the time, will be apparent as we come to the pathological aspects of the subject. Thus advancing carefully, if we reach the conclusion just referred to, with a full knowledge of *all* that it means, from that vantage ground we shall see many of the pathological questions relating to the ocular muscles in a clearer light than would be possible otherwise.

§ 2. **The Geometry of the Globe.**—In order to indicate definitely the position which the eye assumes in its various movements it is necessary to recall certain terms descriptive of the globe itself and certain facts concerning it which, though familiar to most ophthalmologists, are often forgotten or confused. It is customary to consider the eye, like the earth, as divided by three planes at right angles to each other, which produce corresponding circles by their intersection with the globe. First, there is a horizontal plane passing through the center of the cornea, the nodal

points, center of motion, and the optic nerve, cutting the globe in a corresponding horizontal meridian. Second, a vertical plane passing through the center of the cornea, the center of motion, and the posterior part of the globe, somewhat externally to the optic nerve. This cuts the globe in another circle, the vertical meridian. The intersections of these two meridians give us the anterior and posterior poles of the eye.

Third, an imaginary vertical transverse plane passes through the center of motion, cutting the globe at the equator, and is therefore called the equatorial plane. The equator, with the horizontal and vertical meridians, are naturally the three principal or great circles of the globe. The edge of the cornea would form a small circle if it were actually circular, but that is not strictly the case.

The intersections of these meridians give certain well-known axes which it is necessary to mention, because confusion exists concerning one or two of the terms. The vertical axis passes through the two points where the equator intersects the vertical meridian, and the horizontal axis through the two points where the equator intersects the horizontal meridian. The axis which passes through

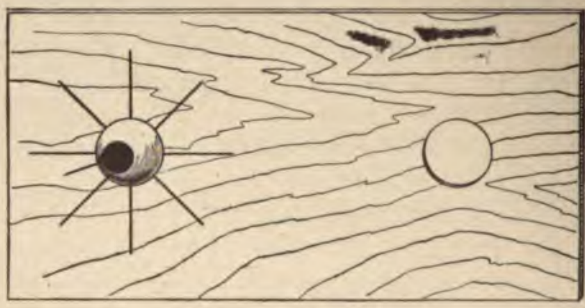


FIG. 93.—Listing's Plane. If we cut a circular opening in a board and in this insert a rubber ball, passing it half way through the opening, the board represents Listing's plane.

the two poles of the eye is called the antero-posterior or the optic axis A A (Fig. 94). Although this line often coincides with the center of the cornea, that is not always the

case. In a subsequent section reference will be made to the angle which the visual axis makes with the optic axis.

Listing's Plane.—In addition to those geometrical planes which cut the globe of the eye as similar imaginary planes cut the earth, there is another plane which we shall find of importance in relation to movements of the globe. It is the so-called Listing's Plane (Fig. 93). *This is a vertical transverse plane passing through the center of motion of both eyes.* It is always considered as fixed and immovable. It coincides with the equatorial plane of the eyes only when the visual axes are in the *primary position*—that is, when they lie in the horizontal plane, are parallel to each other, and are perpendicular to the base line connecting the center of motion of the two eyes (B 264, p. 289). The importance of Listing's Plane will become evident when we

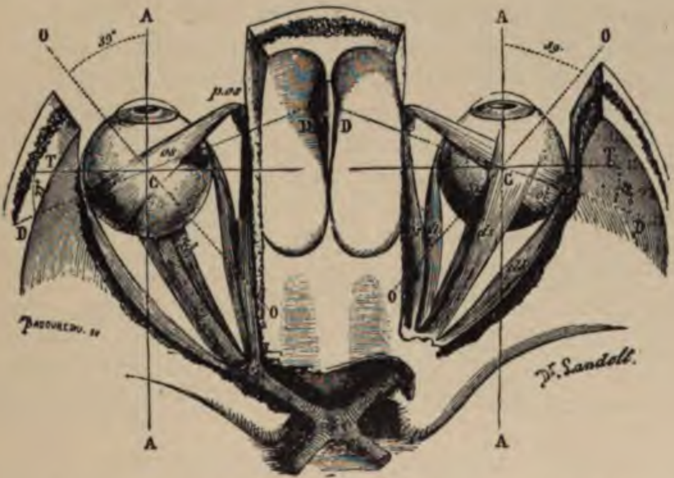


FIG. 94.—Horizontal section, partly schematic, through the two orbits. A A antero-posterior axis, T T transverse axis, D D axis of rotation of the superior and inferior recti, O O axis of rotation of the oblique (Landolt).

see later that every turn of the globe from the primary to a secondary position is accomplished by a rotation about an axis which lies in this plane.

It is well also to recall the position of the axes about

which the globe rotates when it is acted on by certain muscles or groups of muscles.

First, as to the axis of the horizontal muscles. As the center of the insertion of the internal rectus corresponds generally to the horizontal plane, and as the center of the external rectus also corresponds to the horizontal plane, it is evident that the action of either of these muscles is to rotate the eye about an axis which is practically vertical.

Second, the axis of the vertical muscles does *not* coincide with the horizontal axis of the eye. For, as the superior and inferior recti, arising near the median line, pass forward and outward, they are inserted into the globe at an angle of about twenty-five degrees from the median plane. This angle is not really invariable, as the positive statements in some of the text-books would lead one to expect, for, as we have seen, the primary and secondary insertions of these muscles vary very decidedly. It is evident that the axis of rotation of these muscles forms a corresponding angle with the optic axis on the horizontal plane. When therefore the superior rectus, for example, contracts, it does not turn the globe directly up, but up and outward (Fig. 94).

Third, as to the axis of the oblique muscles. In a similar manner, the axis of rotation of the oblique muscles is usually described as making an angle of about thirty-five degrees with the optic axis, but for the same anatomical reasons this statement is only approximately true. This axis, like that of the superior and inferior recti, of course does not lie in Listing's plane, and when the superior oblique, for example, contracts, it does not rotate the globe down, but down and outward.

It is worth while also to glance at a table giving the average measurements of the globe and of the distances within it.

According to Helmholtz we have the

Length of the emmetropic eye..............	23.266	mm
Radius of curvature of the cornea...........	7.829	"
Distance from the apex of the cornea to the anterior surface of the crystalline lens......	3.6	"

Radius of curvature of the anterior surface of the lens	10.0	mm.
Radius of curvature of the posterior surface	6.0	"
Thickness of the lens	3.6	"
Distance from the apex of the cornea to the posterior surface of the crystalline lens	7.2	"

§ 3. **The Center of Motion.**—We know that the action exerted by any muscle is in a plane determined by three points: the origin of the muscle, its insertion, and the center of motion of the eye. The origins and insertions of the different muscles have been already studied. A number of different methods have been suggested by which the center of motion may be determined, and the results obtained vary slightly, but perhaps the simplest and most reliable is that proposed by Donders and Dojer (B 251). This article was evidently considered of special value by Donders, for a large part of it is reproduced almost verbatim in his work on *Accommodation and Refraction* (B 260, p. 186). The method consists in determining the diameter

FIG. 95.—Doubling of the corneal images as seen with the ophthalmometer when measuring the center of motion (Donders).

FIG. 96.—Triangles in the globe by which the center of motion is measured (Donders).

of the cornea, or its half diameter, by means of an ophthalmometer, and then estimating from that diameter where the center of motion lies (Figs. 95 and 96).

By this method it was found that the distance of the center of motion behind the anterior surface of the cornea was

In emmetropia	13.45	mm.
In hypermetropia (about)	13.22	"
In myopia (about)	14.52	"

§ 4. Calculation of the Center of Motion by Means of the Javal–Schiotz Ophthalmometer.

It might be sufficient, after referring briefly thus to the method adopted and the results obtained, to leave the subject here. But some students may care to follow it a step further, making the measurements themselves, and for that reason an additional word is in order, to indicate how the center of motion can be determined by means of the Javal-Schiotz ophthalmometer now so commonly used, at least in America.

For this purpose, it is necessary to place the instrument on a table about a meter and a half or three-quarters in length, and draw the telescope backward from the head-rest until the distance between them measures 1.33 meters. Of course the mires are dispensed with altogether. A small electric light or a candle is placed directly above or below the tube, but in order to focus the cornea, the optical arrangement requires that the tube should be proportionately shortened. One conjugate distance—from patient to instrument—having been lengthened, the other conjugate distance—from instrument to observer—must be shortened.

The easiest way to accomplish this is to unscrew the tube at the point where the larger portion of it joins with the smaller—that is, take out what may be called the slim joint.

It is necessary, therefore, to place a proper eye-piece at the end, in order to see the double image of the cornea distinctly. For this purpose a twenty-diopter glass, or the ordinary eye-piece of the ophthalmometer, can be used, by having a collar fitted to it of sufficient size to adapt it to the larger part of the tube. Such an arrangement gives a clear double image of the cornea, or by changing the distance of the instrument from the patient the two circles of the cornea can be made to overlap each other to any extent desired.

The second modification of the ophthalmometer necessary for this purpose is to attach to it a bar on which to record the amount which the globe turns from one side to the other. For this, we place a small brass bar, which measures about seventy centimeters long by five or six millimeters square, horizontally across the center of the instrument. It happens that the earlier forms of the Javal-Schiotz ophthalmometer have a horizontal slit in the disc, and it is therefore easy to attach the bar by means of a couple of thumb-screws. The rod should be graduated in centimeters from its central point outward in each direction for a distance of about twenty centimeters, and from that point, to its end, in millimeters.

On this bar are two small carriers which slide on the bar at will and serve as objects at which the patient looks. In order to make these more distinct, it is sometimes desirable to attach to each one a bit of paper or other object easily distinguishable.

The third change in the ophthalmometer is to attach to the part against which the head rests, a ring or square which has a hair strung vertically across it, and so arranged that it can be brought close to the cornea under examination. The vertical hair in the ring should also be so near to the cornea that both hair and cornea are focused at the same time, and so adjusted by a slide that the ring can be moved slightly from side to side until it is just opposite the

center or edge of the cornea. Having made these three alterations the procedure is simple.

First, we must measure the diameter of the cornea. To do this the distance between the instrument and the observed eye is increased until the doubling of the image is such that the edge of the one cornea passes through the center of the image of the other cornea (Fig. 95). The distance from the center of the prisms to the center of the cornea is then measured. This distance D E we will call a (see Fig. 97).

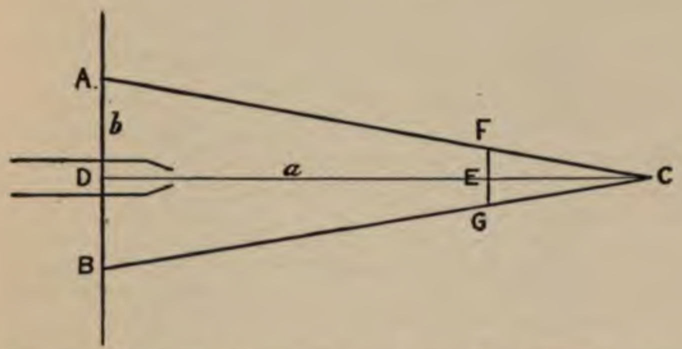


FIG. 97.—Triangle on which calculations are based to determine the center of motion of the globe.

Half of the breadth of the cornea is found in the following manner: measurements show that the ophthalmometer used is so constructed that when an object is placed 330 mm. from the center of the prism the instrument produces a deviation of 2.95 mm. of the image of the object. Hence if the cornea is placed at a distance, a, and is deflected a distance equal to its own half breadth, x, we have the following proportion:

$$330 : 2.95 :: a : x$$

$$\text{and } x = \frac{2.95\, a}{330} \qquad (1)$$

In order to measure the center of motion the patient is requested to fix his eyes on one of the small carriers of the bar, which is placed directly over the center of the instrument; the hair is then adjusted until, on looking through the ophthalmometer, it seems to pass exactly through the center of the cornea. The carrier which the person is still observing is then moved along the bar, until it reaches such a position that as the examiner looks through the ophthalmometer the hair seems just to touch the edge of the observed cornea. The distance from the carrier to the center of the rod—DA or DB— is then measured, which distance we shall afterwards refer to as b (see Fig. 97). It is wise in this connection to perform the same operation on the other half of the bar in

order to check the result. If the observation has been made carefully the two distances should be equal. We are now ready to calculate the center of motion.

FIG. 97.—Let ADB be the horizontal rod, A and B the carriers, FEG the chord of the cornea, C the center of motion. The eye is so placed that FG is parallel to AB and the line CD passes through C the center of motion, E the center of the chord, and D the center of the telescope. Hence let $DE = a$, $EC = y$, $AD = b$. From expression (1), we have $330 : 2.95 :: a : FE$. $FE = \frac{2.95 . a}{330}$ Let $\frac{2.95}{330} = m$, which is a constant for any given instrument, then $FE = ma$. In the similar triangles FEC and ADC, DC : AD : : EC : FE. $y + a : b : : y : ma$. $mya + ma^2 = yb$. $ma^2 = yb - mya = y(b - ma)$. $y = \frac{ma^2}{b - ma}$

If we call m "the deviating power of the prism," then we can express this formula as a rule which in reality is not as complicated as it sounds.

The distance of the center of motion from the transverse chord of the cornea is equal to the quotient of the product of the deviating power of the prism multiplied by the square of the distance from the transverse chord of the cornea to the brass rod, divided by the difference between the distance of the pointers from the center, and the product of the deviating power of the prism multiplied by the distance from the brass rod to the cornea.

The following is a calculation of this rule arranged for logarithmic computation.

$a = 662.5$, $b = 359.3$.

$m = \frac{2.95}{330.}$	log 2.95	=	.469822+0.	
	log. 330.	=	.518514+2.	
			.951308−3	=log. .008938
m = .008938				
log. m	=	.951408−3	b =	359.3
log. a	=	.821186+2		
log. ma	=	.772494+0	= log.	5.9223
				353.38 = (b −ma)
		.821186+2		
log. ma ^{2}	=	.593680+0		
log. (b−ma)	=	.548242+2		
		.045438+1	= log.	11.1029
Add the distance of the chord of the cornea from its anterior surface or the vers. sin of corneal arc			=	2.5
Location of center of motion behind the cornea (radius)			=	13.60+

§ 5. **The Angle Alpha.**—The text-books usually represent the lens and cornea as if both were exactly centered. We have already seen that the former is often

displaced from the position which theoretically it should occupy, and exact measurements also show that the center of the curvature of the cornea does not always correspond

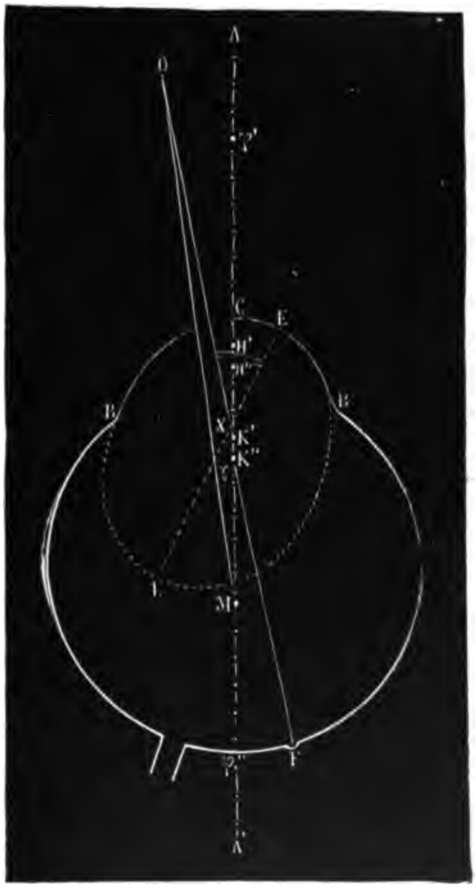


FIG. 98.—Horizontal section of the globe with distortion of natural curvature of the cornea to show the direction of the various axes in the horizontal plane (Landolt).

to the axis of the lens. All have agreed, however, to call the *optic axis* the line which passes through the nodal points of the lens and approximately the center of the

cornea (A A, Fig. 98), and also to call the ***visual axis*** the line which passes from the object O to the *fovea*, OF. Unfortunately confusion has arisen as to the name of the angle which the optic axis makes with the visual axis, and it is well to clear up this point before proceeding farther. When Donders made his important investigations concerning the size and position of what he called the "angle

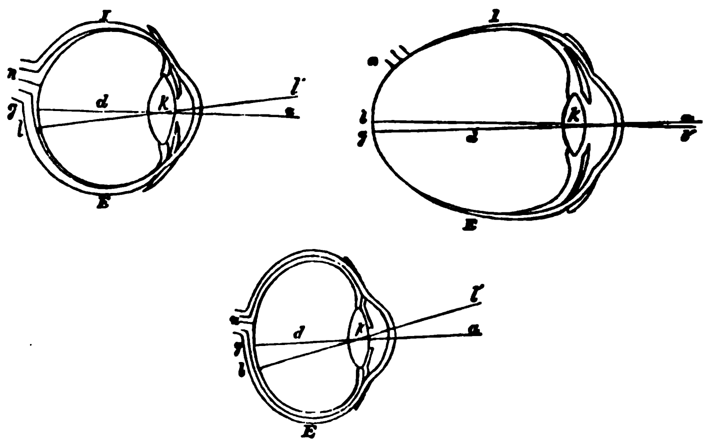


FIG. 99.—The angle alpha in emmetropia, myopia, and hypermetropia. *ag* is the optic axis ; *ll*, the visual axis (Donders).

alpha," he referred to the one which the visual axis makes with the optic axis. Since his time, however, it was found that the apex of the corneal ellipse (E) does not always coincide with a point in the optic axis (C). Hence OXE was called by Landolt and some others the *angle alpha* and OMA the *angle gamma*. But many other writers still describe the angle alpha as the one which the optic axis makes with the visual axis, that is OXA. Maddox (B 263. p. 217) tries to clear up the confusion by describing the "angle alpha of Donders" as one angle, and the "angle alpha of Landolt" as another. In order to be rid of this ambiguity, it seems better to follow the example of Donders, as Tscherning and others have, and retain the term "angle

alpha " to describe the one which the visual axis makes with the optic axis OXA, to agree with Landolt in calling the angle OMA the angle gamma, and then to the angle OXE give an entirely different name—for example, the *angle delta*.

It happens that we have to deal frequently with this angle alpha, but the angles delta and gamma are only of theoretical importance.

The size of the angle alpha varies. In emmetropia it ranges ordinarily from three to five or six degrees or sometimes much more. When unusually large, the eye has every appearance of a divergent squint, although the visual axes may be perfectly parallel. In myopia the angle is less than in emmetropia, in fact it is often reduced to nothing, and sometimes the anterior end of the visual axis falls to the temporal side of the optic axis. In that case the angle is said to be negative (Fig. 99).

§ 6. **Clinical Value of the Angle Alpha.**—Of what importance is the angle alpha and why is it worth while to consider methods for its measurements?

First. Two of the methods of measuring this can also be made use of, with slight modifications, to measure pathological deviations of the eyes, and if given here they need not be described later.

Second. The supposed divergence of some hypermetropes can be shown to be only apparent.

Third. A large angle alpha may act as a predisposing cause of pathological deviations.

There are several methods by which these measurements can be made: one is simple, but only an approximate estimate; others are more exact, but demand time and care.

(a) The easiest method is to estimate the size of the angle from the apparent position of the corneal reflex with reference to the center of the pupil (B 263, p. 216). For that purpose the ophthalmoscope is sufficient. When the observed eye looks straight at the opening in the center of the mirror, the visual axis, of course, passes through the inner side of the observed cornea to the fovea (Fig. 100). If now the angle be zero or very small, the reflex

from the cornea appears in the center of the pupil. If the angle be large, the reflex from the cornea seems to be toward the inner edge of the pupil. If, as may happen in myopia, the angle be negative, then the corneal reflex will be seen nearer the outer edge of the pupil.

In such measurements one must be certain, however, that the pupil of the observed eye is central and normal, and also that the person looks at the opening in the ophthalmoscope. The simplicity of this method gives it great value, not only for estimates of the angle alpha, but also in detecting the degree and forms of deviations, though it must be admitted that these measurements are not exact.

FIG. 100.—Ophthalmoscopic corneal reflections in emmetropic eyes: above with both eyes looking at the center of the mirror; below with both eyes looking to the right, showing a symmetry of the corneal images owing to the angle alpha (Maddox).

(b) Another simple method of measuring this angle, which is also dependent on the corneal reflex, is by means of the perimeter, with an electric light or candle which moves along the arc when that is placed horizontally. Let us suppose the right eye to be under examination. The head having been adjusted in the usual way before the instrument, the patient is directed first to look at the zero point of the arc. If at the same time the light be placed at the zero point, and the examiner, sitting in front, sights over this point into the eye of the patient, the corneal reflex seems to come from the inner portion of the pupil. If, however, the examiner continues to sight over the zero

point while the light is slid along the arc to the left of the patient, and his eye then follows the light, a point is soon reached at which the examiner sees the corneal reflex in the center of the pupil. The number of degrees traversed by the light is the size of the angle alpha.

(c) A more exact method of measuring the angle is to compare the position of the reflex from the cornea with that which comes from the posterior capsule of the lens. This has been already described when considering the position of the lens (page 71). When exactness is desired, this method is certainly the best. For this purpose the ophthalmophacometer of Tscherning is not necessary, the ophthalmometer of Javal with the modifications already described being quite sufficient.

§ 7. **The Relation of Visual Acuity to the Action of the Eye.**—In connection with the geometry of the globe, we may with propriety consider that which determines the direction of the eye when in motion—in other words, the point of fixation of the eye and the acuity of vision. The position which the globe assumes normally is determined by the fact that the sensibility at the fovea is so much greater than elsewhere in the retina, that there is an instinctive desire to turn the eye in such a way that the central part of the image shall fall just at that point. Exact studies made by Uhthoff and others indicate that the smallest space between two points which can be perceived must subtend an angle of about 55 seconds.

This fact has a bearing upon the construction of test types, for, as is well known, most of the letters, especially the square ones, can themselves be resolved into squares, the smallest projecting parts measuring about one-fifth of the entire letter. Therefore, in order to see all the parts of such a letter distinctly, each of these smallest portions must subtend an angle of about one minute, or—exactly—the entire letter should subtend an angle of $55'' \times 5 = 4'.6$. Knowing this, it is easy by simple trigonometry to ascertain what the total height of a letter should be in order to have its smallest portions visible at a given distance. If,

for example, we wish to construct a letter just visible at one hundred meters, we have 100 tan. $4^\circ.6 = x = 133.0$ mm. In like manner we find that the height of a test letter for a distance of 50 meters should be 66.5 millimeters; for 25 meters, 33.3 millimeters, etc.

It is necessary thus to call attention briefly to the well known principle upon which the construction of proper test types depends, because, when measuring the action of the ciliary muscle, physiologically or pathologically, we must know that the object looked at is of the size to be seen readily by the normal eye at a given distance. As far as the types are concerned which are used for distance, it makes comparatively little difference which set is selected out of the several ex-

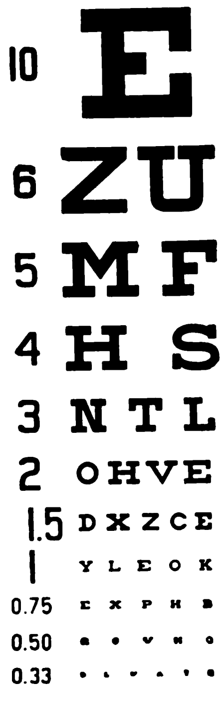


FIG. 101.—Series of test types for the near point.

cellent forms which have been constructed on this plan by ophthalmologists. When making tests at the near point it is desirable, however, to use types which permit the vision to be expressed in meters or fractions of a meter, if we are to make this part of our ophthalmology accord with the rest. Among all the test types ordinarily used for the near point it was not easy to find any which were entirely satisfactory, and accordingly another set was arranged (Fig. 101). They seem to have some advantages.

First, they are constructed on the metric system and bear a definite and convenient relation to each other. They re also in accord with the letters recommended by the Committee of the American Ophthalmological Society (B 266).

Second, the largest is of such a size that it should be seen by the normal eye at ten meters, the next at six, then five, four meters, and down to one-third of a meter, the distance being clearly expressed in the margin of the card. When using these for the near point (p), that can easily be recorded,—$p = 0.5$ or $p = 0.75$, etc., as the case may be.

Third, the detached letters here used are better than words.

Fourth, the tests as a whole are so small that when not framed they can be carried in the pocket, and are always ready for use.

Fifth, the card on which the letters are printed has attached to it, when framed, a thread with several knots, one at 33 cm. another at 50 cm., etc., so that the exact distance at which the types are held can thus be measured easily and promptly.

§ 8. **Suppression of Diplopia is Physiological.**—When both eyes are fixed upon an object in front, evidently all other objects lying in that plane—or indeed anywhere else except in the circle of the horopter—are focused on parts of the retina in the two eyes which do not correspond with each other. This of course produces double vision, and if we were accustomed to take cognizance of all these double images the result would be confusing in the extreme. That is easily seen by pressing upon one eye in any direction, so

as to produce diplopia. The fact is, therefore, that the normal eye is accustomed to suppress those images which do not fall on the fovea, and to such an extent that we are practically unconscious of it. This is accounted for in various ways, and perhaps no better explanation has been given than by what Javal calls "the antagonism of the visual fields." Or, as Tscherning says (B 264): "It is sometimes the images of one eye that predominate, sometimes those of the other, and as long as we see in a part of the visual field images with one eye, those of the other eye are completely suppressed." Javal considers that this has an important bearing on some forms of deviation with which we will have to deal later.

§ 9. **Monocular Position of Rest.**—It is customary to suppose that when one eye is at rest it is in the primary position, but that is not always the case. The observations which we have on this point rather indicate that the tendency of a single eye, when at rest, is to swing from the primary position sometimes inward, or more frequently outward, or outward and upward. Certain experiments also indicate that when a single eye fixes an object and the light is suddenly extinguished, or the object which is looked at vanishes, the globe turns slowly outward a few degrees. Maddox (284) has studied this phenomenon quite carefully with what he calls a *visual camera*. On trying some of the experiments with this camera I have found them interesting, though not apparently of clinical value.

He thinks that when an individual excludes one eye from the visual act, the other apparently tends to swing outward rather more frequently and to a greater degree than inward. This statement apparently contradicts what we find constantly in practice—namely, a slight degree of latent convergence, or esophoria. The position which the eye assumes in sleep also indicates that, as a rule, it turns up and outward. It is frequently stated that eyes which have become blind almost invariably turn outward. That, however, is not quite true, for an examination of one hundred and twenty-one pupils of the New York State School for the Blind with reference to this point showed

that there were almost as many cases of abnormal convergence as of divergence, though sometimes the amount of nystagmus or the degree of distortion of the globe made it rather difficult to decide just what position a given eye did assume. We must conclude, therefore, that the monocular position of rest seldom corresponds to the primary position.

CHAPTER II.

§ 1. **One Eye in Action but not Necessarily in Motion (Accommodation).**—Earlier students supposed that accommodation was produced by elongation of the globe, advancement of the lens, contraction of the pupil, increase in curvature of the cornea, etc. Without delaying to consider how this act is not accomplished, let us see briefly in what it does consist. We all agree now that this is by a contraction of the ciliary muscle, and as a result, the lens in some way becomes more convex (Fig. 102). It is still a question, to some, however, whether the zonula is relaxed, or whether it is tense in extreme accommodation, and also as to the exact form which the lens assumes when increasing its convexity. There are two opposing views concerning the condition of the zonula. The first of these, and the one accepted at present by most physiologists, is the so-called Helmholtz theory of accommodation. That may be stated briefly as follows:

When the individual looks at a far point, the ciliary muscle is relaxed, but in such a manner that the fibers of the zonula are held tense, and this traction on the lens causes it to become thin and adapted to focusing parallel rays upon the retina. But, when the individual looks at a near point, the contraction of the ciliary muscle draws the entire ring of muscle toward the lens, producing a *relaxation* of the zonula. The ultimate fibers of the lens, being then relieved from pressure, tend to straighten themselves out and make the lens more convex. Or, according to this view, the zonula is tense when the eye is adjusted for the distance, and it relaxes more and more in proportion to the degree of accommodation for a near point.

On the other hand, according to the view which has been

more recently elaborated by Tscherning, it is considered that when the eye is adjusted for distance it is entirely at rest. The ciliary muscle is relaxed, the zonula is also relaxed, and the convexity of the normal lens is then just sufficient to produce a clear image upon the retina of the normal eye. When, however, an effort is made at accommodation, the contraction of the ciliary muscle produces a *tension* of the zonula, and this, of such a character as to cause an increase in the convexity of the anterior surface of the lens, or, as Tscherning calls it, "a temporary anterior lenticonus." *All agree, therefore, that accommodation is due to an effort on the part of the ciliary muscle.* For our purposes it might be sufficient to state the important fact that accommodation is essentially an active condition. But as it is necessary to

FIG. 102.—Change in the eye during accommodation (Helmholtz).

make frequent reference to accommodation in all of the physiological and especially in the pathological part of these studies, it is therefore desirable at this point to review briefly the different factors which enter into that act in order that there may be no question as to what is meant by the term "accommodation." Let us, therefore, consider the phenomena which take place.

First. The pupil, which is dilated when viewing distant objects, becomes contracted when the eye is adjusted for a near point. Of this there is no question.

Second. The pupillary edge of the iris apparently changes its position. Helmholtz thinks that it advances. Tscherning (B 303) considers that more apparent than real, and figures

a section of the anterior chamber as in the accompanying diagram (Fig. 103).

Third. The ciliary muscle contracts and this contraction is generally in proportion to the degree of accommodation. This is also agreed to by all, the proofs being:

(A) The subjective sensation.

(B) The phenomena produced by a cycloplegic.

(C) The phenomena produced by paralysis of the motor oculi.

Fourth. The effect which that contraction of the ciliary muscle has upon the zonula is not yet fully understood.

FIG. 103.—Changes of the anterior chamber during accommodation. *a* Repose. *b* Accommodation. (Tscherning.)

Several men who have studied the question most carefully and exactly still differ among themselves as to whether the zonula is then relaxed or is made more tense.

In favor of the former view we have the following contentions:

(A) The entire lens seems to fall toward the more dependent portion of the eye. Hess (B 327) and Heine (B 314) consider this as fully established, while Tscherning accounts for the appearance by a change of the position of the entoptic images. It is a point not easy to decide.

(B) Under favorable circumstances, when accommodation begins, the entire lens can be seen to shake or tremble with motions of the eyes or head. Although Hess was the first one to call attention to the meaning of this phenomenon, it is so easily observed that it is surprising its significance had not been recognized before. It is demonstrated best in some case in which there is a small but well-defined opacity of the lens near its center, such as we see, for example, in certain cases of injury or in forms of well-marked lamellar cataract. If we first drop into such an eye a moderately strong solution of cocain, the dilatation of the pupil enables the opacity and a considerable portion of the lens to become visible. Then if a solution of eserin be applied and after a few minutes the lens be examined by oblique illumination or with the ophthalmoscope, or even with the naked eye, it is possible to observe that each time the globe makes a sudden motion as the patient looks to the right, left, up, or down, the cataractous opacity, and the entire lens with it, can be seen to shake and tremble. The appearance presented under such circumstances is very similar to that which is observed when for any reason the vitreous has become fluid. In this experiment it should be noticed that when the pupil

contracts to such a degree as to bring the anterior capsule in contact with the iris, or apparently near to that point, this shaking or trembling phenomenon is no longer visible.

In an interesting case of aniridia with central opacity in the lens, which was recently reported by Grossman (B 325), this trembling of the lens at one stage was unusually well shown.

It is possible with proper care and appliances to observe a slight motion of the lens even in a normal eye. Thus persons accustomed to use the ophthalmoscope or trained to experiments in optics can increase or decrease their accommodation at will. Now if the observer focuses the anterior surface of the lens in such an eye with a Zeiss loupe, and notices carefully the *chagrin* already described, and the subject be asked to adjust his accommodation first for the distance, then for the near point, altering it rapidly, and at the same time to move the eye quickly, a slight tremulous motion can often be detected.

The foregoing facts undoubtedly indicate that contraction of the ciliary muscle *relaxes* the zonula.

A B

FIG. 104.—Changes in the position of the lens in Grossman's case of aniridia.

A. Position of the lens with accommodation relaxed.

B. Position of the lens after instillation of eserin.

The spot in the center is a small point of capsular opacity.

On the other hand certain observations indicate that the zonula is made *more tense*.

(A) The entire lens sometimes moves upward and slightly inward. This was well shown in Grossman's case (Fig. 104).

(B) Some think that tension of the zonula increases the convexity of the anterior surface (Fig. 105). This observation by Crzellitzer (B 306–307) and others by Stadfeldt (B 309) apparently confirm the view of Tscherning that tension on the zonula may produce an anterior lenticonus.

The method of Crzellitzer (B 306) of holding the lens is suggestive to future students of the question. He prepared a small instrument, as represented in Fig. 106, whose object was to hold a lens in the central opening in such a way that traction could be made at its edges in different directions at the same time. The lens was then removed from the eye of an ox, and being suspended in the center in the inner circle of the instrument, the screw B was turned. Under these circumstances he thought that while the posterior

surface remained practically stationary, the anterior surface became more convex. The validity of this experiment, however, is denied by Hess.

The act of accommodation in the eye of the lower animals furnishes apparently a very promising field from which to collect data concerning the behavior of the ciliary muscle and its effect upon the zonula. This is especially true of reptiles, batrachians, etc., because in them, muscle action persists a considerable time after the eye has been isolated from the body. This has

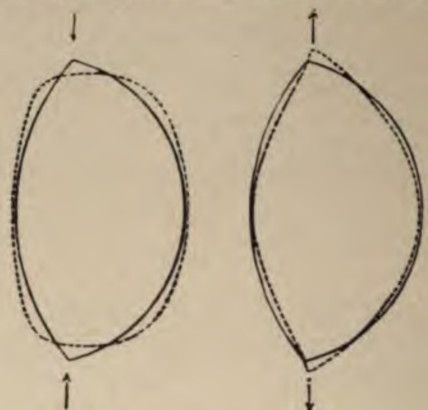


FIG. 105.—Lens of the ox, twice enlarged. The dotted line indicates the form which the crystalline lens assumes: (A) by a lateral pressure (B) by traction exerted on the zonula. The arrows indicate the direction of the forces (Tscherning).

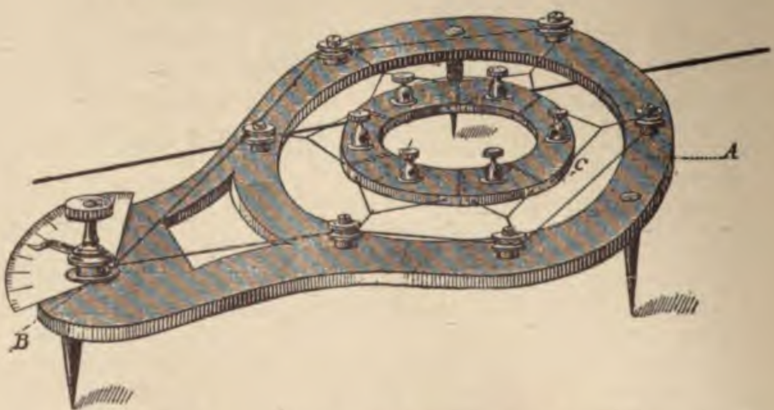


FIG. 106.—Arrangement for making tension on the zonula in order to observe changes in the lens (Crzellitzer).

been carefully studied by Beer (B 319). A striking demonstration of accommodation in the eye of a snake was made by him at a meeting of the Ophthalmological Section of the New York Academy of Medicine in October, 1904. Briefly stated, the method consisted in decapitating the animal, quickly removing the eye, placing it beneath a microscope with its lens vertical and about in the center of the field. Then, a fine wire having been brought in contact with the muscles which adhered to the side of the globe, a current of electricity was passed through the eye from a battery of three small cells. The experiment was most suggestive and interesting. With the eye in this position the iris and lens could be seen distinctly. Whenever the current was closed, the pupil immediately contracted and the lens appeared to jump forward as its anterior surface became more convex.

FIG. 107.—Method in which the lens is suspended by the above instrument.

In view of the testimony now before us, it is almost presumptuous for one who has not devoted himself for a considerable time to studying these phenomena to express an opinion. The evidence on both sides is here given with the hope that it may induce others to pursue the study farther. From the facts thus far collected it must be conceded, how-

FIG. 108.—Relative position of the reflections from the cornea and from the two surfaces of the lens during the act of accommodation. A represents their situation in the eye accommodated for distance; B, in the eye accommodated for near objects. In both, a is the image reflected from the cornea; b, that from the anterior surface, and c, that from the posterior surface of the lens (Donders).

ever, that *the balance of evidence favors the conclusion that the zonula does relax* and, in a word, that the so-called Helmholtz theory, perhaps with some modification, is nearest to the truth.

Fifth. Whatever the condition of the zonula may be, it is certain that the anterior surface of the lens becomes more convex. All agree on this point, though there is a marked disagreement as to the exact form which that surface assumes. To determine this, we depend principally upon the reflections from the anterior surface of the lens during the act of accommodation (Fig. 108).

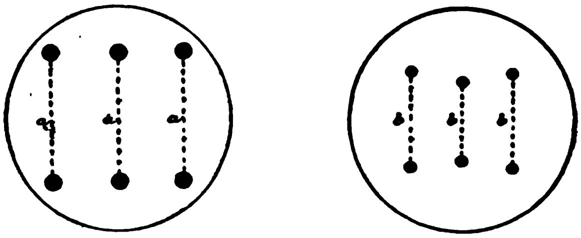


FIG. 109.—Change in the form of the anterior surface of the lens shown by the change in the relative position of the reflections from six points of light. Three of these points are in one horizontal line, and three other points of light directly below are also in a horizontal line. The diagram on the left shows the position of these six reflections when the lens is in a state of repose. The six points in the diagram on the right show the relative position of these reflections when the lens has been accommodated to a near point (Tscherning).

Inasmuch as a strongly convex mirror gives a smaller image than one of less curvature, and as in B the image reflected from the anterior surface of the lens has become smaller than it was in A, the inference is that the curvature of the anterior surface increased. Helmholtz supposed that this increase in the curvature was equal in all parts of the anterior surface.

A more exact study of these reflections from the anterior surface of the lens, however, tends to show that the increase in the convexity is really unequal, being greater in the center than near the equator. Thus Fig. 109 gives the reflections, from the anterior surface only, of the lens, of six different lights: *a* is when the eye is adjusted for distance, and *b* in accommodation.

These reflections from the upper horizontal line of lights do not approach in an equal degree those from the lower horizontal line, but instead, each line of the reflections tends to arrange itself in a curve with its convexity toward the center of the lens. For the proper elaboration of this point the student must turn to the article by Tscherning (B 291). The evidence tends to show that a real anterior lenticonus is produced, as Tscherning states (Fig 110).

FIG. 110.—Change in the form of the lens during accommodation. The continued line indicates the shape of the lens in a state of repose. The dotted line shows the shape of the lens with seven diopters of accommodation (Tscherning).

Sixth. The posterior surface possibly increases its convexity. Helmholtz considers that probable. Tscherning is doubtful, and the experiments of Hensen and Voelckers (B 289), which are cited by Landolt (B 328) as to the movement backward of the posterior capsule, are not as conclusive as they appear. In a word, it is not certain that the posterior surface moves at all.

It is worth while to consider the act of accommodation thus in some detail in order to appreciate what we do know, and what we do not know concerning it. Evidently the question whether the zonula is contracted or relaxed is not of as great practical importance as might at first appear. As all agree that these changes depend primarily upon a *contraction of the ciliary muscle*, we see how accommodation is essentially *an active*, and *not a passive* process. The amount which can be exerted may depend on the age of the person, on the condition of his refraction, and on various other factors, but it always demands an effort. We shall see later that abnormal contractions and relaxations of the ciliary muscle produce forms of muscle imbalance which are of much

importance clinically, and we can deal with these more intelligently after even this hasty review of our data concerning the physiological act of accommodation.

§ 2. **The Range of Accommodation** is the well-known term to denote the amount of accommodation of which an eye is capable. Thus if an emmetrope whose accommodation is at rest when looking at a distant object can also see a point distinctly which is only one-tenth of a meter in front of the eye, we say that he has a range of accommodation of ten diopters. This is often represented diagrammatically, as in Fig. 111, and a similar line will be used frequently in the graphic representation of muscle balance and imbalance.

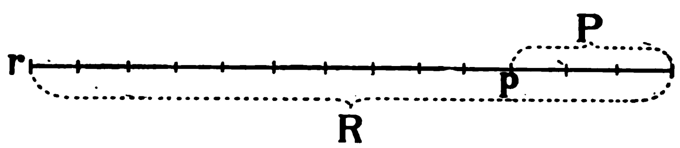


FIG. 111.—Diagram showing the range of accommodation. p is the near (proximate) point. P, distance of the proximate point from the nodal point of the eye. r is the remote point. R is the distance of the remote point from the nodal point of the eye.

If, however, the person has a hypermetropia of two diopters, he must exert that amount of accommodation in order to see even a distant object distinctly, and if he can also see a test object at a distance of one-tenth of a meter, then his range of accommodation is twelve diopters. These well-known facts are referred to only for the sake of completeness.

Of the various methods for measuring the nearest point of clear vision, the most usual one now, is to ascertain the nearest point at which suitable test letters can be seen distinctly. Instead of letters Donders (B 260) used a series of fine wires, to which a tape measure was attached, and Landolt suggested placing around a candle flame a cylinder perforated with small openings. The nearest point at which the individual could distinguish these openings as separate dots indicated the proximate limit of the range of accommodation (Fig. 112). When test letters are

exactly constructed, however, and reduced to the proper size by photography, if necessary, they are as accurate as any other test objects for the near point, and much the most convenient for clinical purposes.

FIG. 112.—A simple arrangement for determining the near point (Landolt).

The range of accommodation is modified by age. Although this fact also is well known, attention is called to it here because it will be necessary to refer frequently to its bearing on certain abnormal conditions of accommodation occurring with presbyopia which give rise to muscle imbalance. In this connection it is worth while to recall the familiar diagram of Donders. In Fig. 113 the figures at the top represent the age of the individual, those on the left represent the range of accommodation in diopters from infinity to 20 diopters above, or from infinity to 8 diopters below. From this we see that at 10 years of age the normal eye can accommodate about 14 diopters, at 30 years of age about 7 diopters, and at 55 less than 2 diopters. At 75 the power of accommodation is practically lost, and after that a weak convex glass may be necessary for clear vision even in the distance. The foregoing relates to accommodation with one eye only, or what Donders called monocular accommodation. He made a distinction between this and binocular accommodation, but the basis of this difference has recently been disputed by Hess (B 329). A discussion of that point would require too long a digression here. Suffice it to say that the binocular range can probably be considered the same as the monocular.

§ 3. **How a Lens before the Eye Affects its Focal Power and therefore its Accommodation.**—In testing for relative accommodation, as will be done later, if we wish to be exact we must be ready to calculate the effect which

a glass of a given strength has on the focal distances of the eye. But as this affects the power of accommodation it will cause less confusion to dispose of the question at this

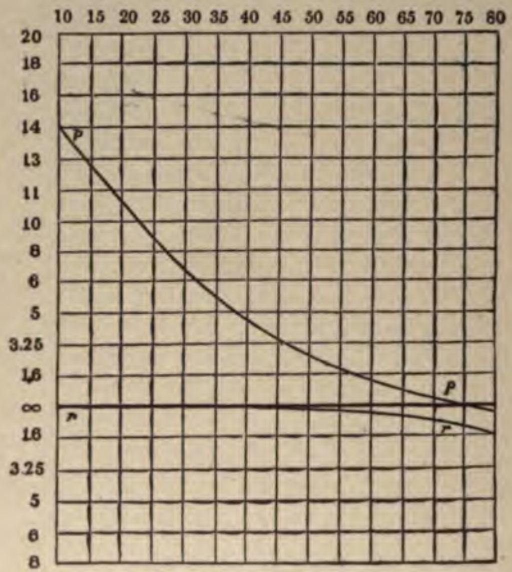
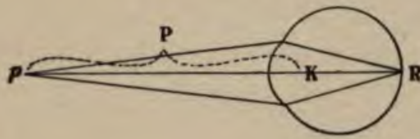


FIG. 113.—Diagram showing the range of accommodation at various ages.

point. In this connection most readers will recall the formula given by Donders, (B 260, p. 144). But as there are several misprints in that part of the English edition, the method of calculation is given here.

In Figures 114, 115, 116 let P represent the distance from the nodal point K to the point p, and P′ the distance from K to the point p' and d the distance of the lens from the nodal point. In these formulas p is the point looked at, while p' is the point for which the eye is adjusted. $\frac{1}{F}$ will be the number of the glass l, and F its focal distance. We must remember that the power of a lens or system is equal to the difference of the reciprocals of

the distance of any two conjugate points when those two points are on the *same* side of the lens, and therefore have, as we say in optics, "like signs" and equal to the sum of the reciprocals when the two points are on



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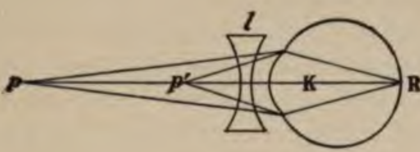

116

FIGS. 114, 115, 116.—How a lens before the eye affects its focal distance.

opposite sides of the lens—that is, have opposite signs. If a *convex* lens be placed before the eye, then the formula follows:

$$\frac{1}{F} = \frac{1}{P - d} - \frac{1}{P' - d} \quad (1)$$

$$\text{or } \frac{1}{P' - d} = \frac{1}{P - d} - \frac{1}{F} \text{ or } \frac{1}{P - d} = \frac{1}{P' - d} + \frac{1}{F}$$

Or it may be said that if the rays coming from p (Fig. 115) were given additional convergence by the glass lens $\frac{1}{F}$ then they would appear to come from the farther point p'.

Let us next see what happens when a *concave* glass is placed before the eye (Fig. 116). When the two points p p' are again on the same side of the lens they are + signs, and therefore the power of the system of the glass lens and

the lens of the eye is expressed by the same formula (1). But in this case $\frac{1}{P'-d}$ being larger than $\frac{1}{P-d}$ the value of the sign of $\frac{1}{F}$ is negative, as follows:

$$\frac{1}{P'-d} = \frac{1}{P-d} + \frac{1}{F} \text{ or } \frac{1}{P-d} = \frac{1}{P'-d} - \frac{1}{F}$$

That is to say, if the rays emanating from p were made more divergent by the glass lens $\left(\frac{1}{F}\right)$, then the rays would come to a focus nearer by—namely, at p'.

This, with the preceding formula, we will have occasion to use in the measurement of relative accommodation.

§ 4. **Measurement of the Pupillary Reaction for Physiological and Clinical Purposes.**—Whoever undertakes to examine the literature of pupillometry is soon impressed with three facts:

First, by the large number of ingenious and careful studies which have been made to determine the size of the pupil;

Second, by the comparatively small number to ascertain the rapidity and degree of variations in its size, or the causes which produce these variations;

Third, by the fact that, while these methods of investigation are well suited to laboratory experiment, they are so poorly adapted to clinical use that practitioners do not avail themselves of the results obtained, in spite of the importance of the symptomatology of the pupil.

In this connection it is only possible to indicate briefly the various factors in the problem of pupillometry, and to refer to an instrument which has proved of at least some assistance in studying this question.

In all measurements of the pupil there are of course two aspects of the problem, the pupil and the instrument with which it is measured. The variations of the former and the imperfections of the latter constitute the difficulties presented. It should be remembered at the outset that the size of the pupil taken by itself is of comparatively slight importance, varying as it does in different individuals and being smaller in advanced life than in youth. Thus in young people from fifteen to twenty it is about four (4.1) millimeters, and in persons of fifty or more, about three millimeters in diameter.

With this fact determined as to the size of the pupil, let us review briefly the main causes which produce changes in its diameter.

First, we naturally think of variations due to intensity of illumination. That means of course that any measurements to be accurate must have a definite relation to photometric standards. For very exact measurements a photometer is an undoubted necessity, but Schirmer says (B 349, p. 12) that "if the window be covered with two white curtains, which either alone or together can be drawn down, the amount of illumination can be sufficiently regulated." This is also sufficient for most of the clinical examinations made to determine whether or not the iris still retains a considerble amount of mobility.

Second, we know that the pupil also contracts with all efforts at accommodation, and this means that in any of these measurements the person must look at a distant object.

A third group of causes tending to vary the size of the pupil relates to the respiration and circulation. We know that the pupil dilates with deep inspiration and that to a certain extent it is influenced by variations in the pulse and blood pressure. With a little care, however, an intelligent subject can be taught to breathe so regularly that, barring pathological conditions of the circulation, this group of causes can be eliminated as a factor in the variation of the size of the pupil.

Finally, varying conditions of the nervous system, especially those involving the sympathetic, produce differences in the size of the pupil. These may be the temporary effect of fear, surprise, or other emotions, or the more lasting changes from lesions of the motor oculi. Moreover, each of these different groups of causes is often influenced by other causes which are still unknown.

Having thus glanced hastily at the principal factors which tend to change the size of the pupil, let us pass next to an instrument with which measurements of these variations can be made—exactly enough, at least, to assist in conclusions physiological as well as clinical.

The accompanying illustration (Fig. 117) shows a microscope arranged especially for this purpose (B 345).

The tube is mounted horizontally on a firm tripod attached to an upright bar. As this bar can be lengthened or shortened, the microscope can be lowered or raised, and

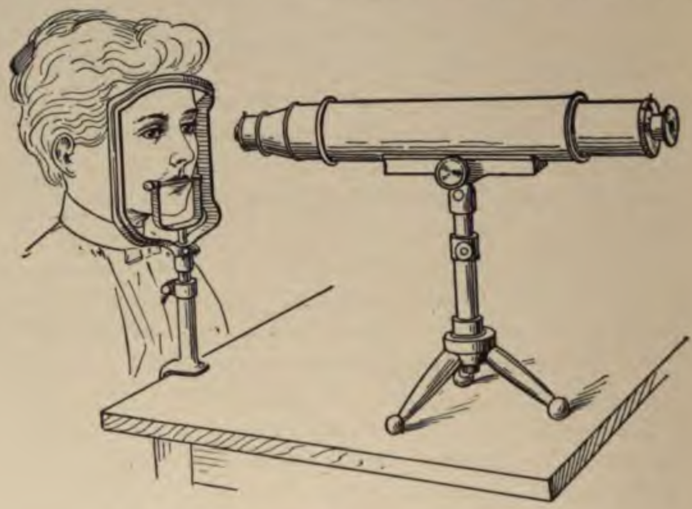

FIG. 117.—Horizontal ophthalmic microscope.

swings horizontally on the axis of the bar. There is a hinge joint allowing the elevation or depression of the tube at any angle, and by means of a rack-and-pinion adjustment it can be pushed forward or backward. In a word, the instrument can be brought at once into any position desired.

There are two eye-pieces. One has a focal length of about nine centimeters, and gives a minimum amplification of twenty diameters to a maximum of fifty, according to the position of the draw tube. The other eye-piece has a focus of 2.5 centimeters, giving a minimum amplification of fifty diameters or maximum of about one hundred and twenty-five. A micrometer eye-piece enables changes in the size of the pupil to be measured with accuracy.

When making an examination, the patient faces the instrument, the eye being approximately near the focus of the objective. The results are best if the chin is placed on a

head-rest, with the teeth fixed in a Helmholtz bit. But for the usual tests for physiological or for clinical purposes it is sufficient to have the person rest his elbows on the table, and then support his chin on his hands.

Ordinarily daylight is sufficient, but if specially good views are desired they can be obtained by bringing a shaded electric light within a foot or two of the patient's head, or by allowing the light coming through a double convex lens to fall obliquely on the eye. While these details are given concerning the most desirable position of the patient and the degree of illumination, it should be borne in mind that such care is by no means essential for clinical work.

The patient having been seated, the head adjusted, and the light arranged, the objective is brought within a few inches of the eye, and almost immediately the direction and the focus are obtained. The view presented is quite striking to one who for the first time uses a microscope in this way, even though with the ordinary pocket lens we are accustomed to see something similar to it every day.

When the pupil is somewhat dilated in a diffused moderate light we usually find it freely movable, so that within thirty seconds it is possible to count at least two or three strong, or what may be called maximum contractions, four or five moderate or minor contractions, and as many or more very slight or minimum contractions. Usually each contraction is followed by a corresponding dilatation, but this is not always the case, two or three contractions sometimes following each other in succession before the occurrence of a dilatation equal to or greater than the three together. Naturally there are decided variations both in the number and the degree of these changes, but a little experience enables one to recognize them, and to establish for himself, at least, a normal standard which is interesting and new to one familiar only with those movements of the iris which are visible to the naked eye.

Of course, the contractions of the iris are by no means always the same, its behavior in one thirty seconds being entirely different from that occurring in the next half minute. Usually, however, after a few careful observations it is

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possible to determine the characteristics of any given pupil, whether normal or abnormal, and at least approximately the character and degree of any variation from the average. In this way it is possible to differentiate the following types of pupillary reaction.

First. What may be considered the normal pupil, this being about such a diameter as just described, and one where the reactions also are of the degree and frequency already indicated as normal.

Second. A pupil unnaturally large or unnaturally small with:

A. An unusually large number of maximum contractions.

B. An unusually small number of maximum contractions.

C. An unusually large number of minimum contractions.

D. An unusually small number of minimum contractions, or

E. With combinations of these types.

The thanks of the profession are due to such painstaking workers in this field as Schirmer (B 349), Bielschowski (B 350), and others, but most of these interesting studies have been made as laboratory experiments and rather to determine the physiological size of the pupil than its average behavior under abnormal conditions. When, however, greater care in measuring the pupil is taken by the ophthalmologist, he will be surprised to see how much has escaped his attention, and he will be apt to strive for greater exactness in observing pupillary reaction.

Later in our study of the anomalies of accommodation special effort will be made to separate, whenever it is possible, cases of excessive accommodation from those in which the power of accommodation is insufficient. In doing this we shall find, as a rule, that in excessive accommodation the pupil is comparatively small and the variations in its size neither many nor great. On the other hand, when the power of accommodation tends to be actually insufficient, or insufficient in relation to the resistance to be overcome in that individual case, the pupil is more apt to be rather large and to show considerable variations. The type of the latter is seen sometimes in the rather large pupil of hypermetropia, that condition of the refraction producing

what may be called a relative insufficient accommodation. The clinical importance of this will be stated later and should not be overestimated because of its mention now.

§ 5. **Irregular (Astigmatic) Contraction of the Ciliary Muscle.**—Most of the older text-books teach that when a motor impulse is sent to the ciliary region all of the muscular fibers contract in absolutely the same degree at the same time—in other words, that the force exerted upon the edge of the capsule is exactly the same in all directions. Some of the most recent observers still incline to doubt the existence of astigmatic accommodation. But there are several facts which indicate very strongly that such contraction of the ciliary process does occur, at least in certain cases.

1st. It is entirely possible from the anatomical arrangement.

2d. Exact measurements of the contraction in other muscles show that there is frequently a difference in the degree of tension in different fibers.

3d. As certain branches of the third nerve are sometimes paretic or "insufficient," leaving the muscles supplied by other branches in an entirely normal condition, so it is probable that part of the filaments which go to the ciliary muscle may also remain in a normal condition, while others may be less or more active, thus producing irregular action on the zonula.

4th. A significant fact pointing to the ability of the ciliary muscle to overcome an existing astigmatism is met with frequently in the consulting room. For example, we find that although the individual can read $\frac{6}{6}$ without difficulty and insists that the lines of the astigmatic chart are all of equal size and clearness, yet examination with the ophthalmometer, with the ophthalmophacometer, and with the shadow test shows the presence of a very decided astigmatism. Astigmatic accommodation is the simplest and most rational method of explaining this difference. Or we may find subjectively a low degree of astigmatism in certain meridians, whereas the objective tests indicate that its axes are in still other meridians.

Moreover, it can be demonstrated experimentally that the increased convexity of the lens during accommodation is of such a form, sometimes at least, as to compensate for an irregular curvature of the cornea. This point was first established by Dobrowolsky (B 352). He measured the amount of corneal astigmatism in his own eye, and then ascertained by other measurements that the form which the lens assumed during accommodation was such as to neutralize this, at least to a certain extent. Similar observations have been made by Woinow (B 353).

5th. Another observation which points towards the existence of astigmatic accommodation is also of a clinical character, but does not depend upon the clearness of the image. This is the sensation of the patient. It is an every-day experience that the correction of an astigmatism lessens discomfort and ocular headache. The relief indicates that the symptoms were due to an effort of some of the fibers of the ciliary muscle to do what the glass did for them.

In view of the testimony thus presented, it seems that the balance of evidence is strongly in favor of the conclusion that there does exist an astigmatic accommodation which in some individuals, at least, is not only measurable but exceedingly well marked. This is not simply in what we may call physiological conditions, but in the pathology of muscle imbalance irregular accommodation is undoubtedly an important factor.

§ 6. **How to Measure the Effects of Cycloplegics and Mydriatics.**—When considering the anomalies of accommodation we shall find frequent references to the effects of atropin or eserin, especially after the employment of so-called minimum doses. It is proper, therefore, to enter into a little detail concerning the form in which these drugs can best be used, and their physiological effects.

At the outset it should be observed that solutions are uncertain and not to be relied upon for exact measurement. No matter how accurately a solution is made, it is apt to undergo changes in a short time by evaporation or deterioration. Even when it is perfectly fresh we cannot be certain

that a definite amount reaches the conjunctiva or is absorbed.

Again, drops differ in size, and even when a single drop of average size is applied to the conjunctiva, the tears may cause more or less to be washed away, or it may pass off at once through the canaliculi if they happen to be unusually large. A much more exact method of application is by means of the *ophthalmic discs* now made by several reliable pharmacists. In the experiments here referred to these discs have been used.

When attempting to observe the effect of a certain dose of a cycloplegic or myotic it is necessary to have proper appliances for taking the readings and recording the results. These are:

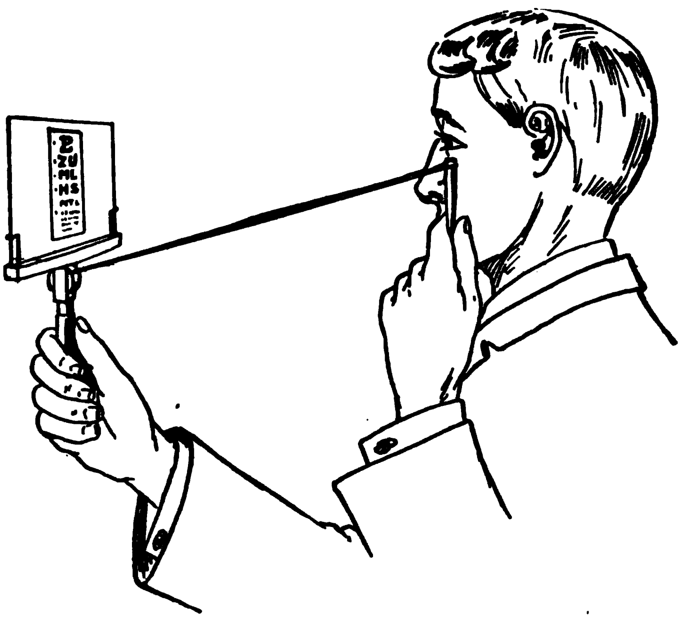


FIG. 118.—Testing the nearest point of clear vision.

(a) Types for testing the nearest point of clear vision. A series of such letters has been already described, the smallest of which should be seen at a distance of 33 centimeters. When we wish to test young subjects, or those who have an accommodation greater than three diopters, we should theo-

retically make use of still smaller letters. As such types are used for measuring the range of relative accommodation, they will be found described in the chapter relating to that subject. The fact is, however, that the smallest letters of the series already figured, are sufficient for most of the measurements necessary in the consulting room.

(b) We require also a suitable measure of the distance at which the type is held. The arrangement used for this purpose consists essentially of the rack of a stereoscope which, on each side of the horizontal bar, has the uprights to hold the card, and below the center of the cross-bar, a firm handle. The latter is bifurcated near its attachment to the cross-bar, and between the arms there is placed a measure graduated in centimeters and in diopters and rolled on a spring. The ring fixed on the end of the measure has a second handle attached to it, that one being much smaller than the first (Fig. 118).

(c) A measure of the size of the pupil. The most accurate one for this is the horizontal ophthalmic microscope already described, but for all ordinary purposes it is quite sufficient simply to hold a millimeter measure in front of the eye and as close to it as possible.

(d) Finally, the record is kept best on charts divided into squares. A convenient form for these is seen in Figure 119. This indicates the number of minutes after the application is made, while the other blank (Fig. 120) shows the number of hours (or of days) required for the disappearance of the effects of the drug. While these charts are extended upward to allow for twenty diopters of accommodation, such measurements evidently cannot be made with ordinary type, although with full doses of eserin in young people the near point approaches nearer than is ordinarily supposed. For clinical purposes, therefore, especially when recording the effects of a cycloplegic, only that portion of the chart is necessary which is near the zero line and they are thus represented in most of the diagrams. It would be unnecessary detail to illustrate such simple blanks were it not that in careful clinical work these are as useful as the blanks for recording the field of vision.

Before beginning an observation, it is essential to determine the refraction of the eye and the condition of the accommodation. For the novice, it is well to commence a measurement just at the beginning of the hour or at some multiple of ten minutes past the hour, for then less confusion arises concerning the number of minutes after the application.

The details of such a test are as follows: Having applied the disc to the conjunctival sac, it is unnecessary to make any measurement for the first ten or twelve minutes. After that, it should be repeated about every five or ten minutes or more frequently for at least half an hour, a longer interval being sufficient for a minimum or a weak dose than for a full one. The procedure consists simply in ascertaining the nearest point at which the patient can read the finest type. The details of the measurement itself are simple. Let us suppose that the left eye is to be tested. The person under examination closes the right eye, takes in his left hand the small handle to which the tape of the measure is attached, the end of the measure being held near the outer canthus and close to it. At the same time he holds the larger handle in his right hand and approaches the card to the nearest point at which the smallest letters can be distinguished. This distance can be immediately read off on the tape in centimeters or in diopters. Thus when a young person with normal eyes recognizes print No. 0.25 at a distance of 25 centimeters, of course he exerts 4 diopters of accommodation. If he can read correspondingly smaller print at 20 centimeters, then he exerts 5 diopters, etc. When the atropin begins to have its effect, as the lens becomes less convex and the near point begins to recede, it is found that this first print is held farther and farther away until it becomes impossible for the person to read it at all. Evidently, therefore, we must pass to the next larger size of the test type. If he can see print 0.5 at 50 centimeters he can still exert 2 diopters of accommodation, and so on until finally, when he only sees print 6. at 6 meters, the accommodation is entirely relaxed. This is all simple enough in theory. The practical fact is, however, that in making these tests it almost never occurs that the

ability to read a given type corresponds with the recession of the near point. This is for the reason that we seldom find an absolutely emmetropic eye.

In making these measurements we often find that the subject can read the 0.25 print at 25 centimeters or 0.50 at 50 centimeters. But as the relaxation of the accommodation

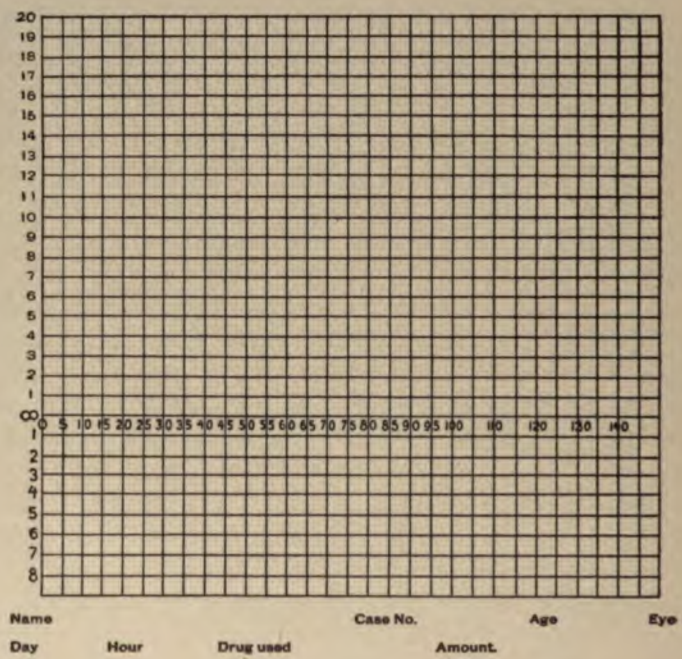


FIG. 119.—Blank on which to record the immediate effect of a cycloplegic or myotic.

proceeds he cannot read the 1. print at one meter. In that case, the only thing to do is to make note at the top of the chart of the smallest print which can be read at that distance, both with and without correction. Then, when plotting the results, account must be taken of these variations from the normal condition.

In spite of the utmost care, there are certain sources of error in these measurements. We are not certain that the manufacturer of the medicated discs is accurate in his meth-

ods, and, even if that be the case, there is always present a degree of susceptibility to the drug, which, as we know, varies in different individuals. When, however, all these sources of error are taken into account, we find them in practice so slight that with a little care there is quite a remarkable degree of regularity in the curves obtained.

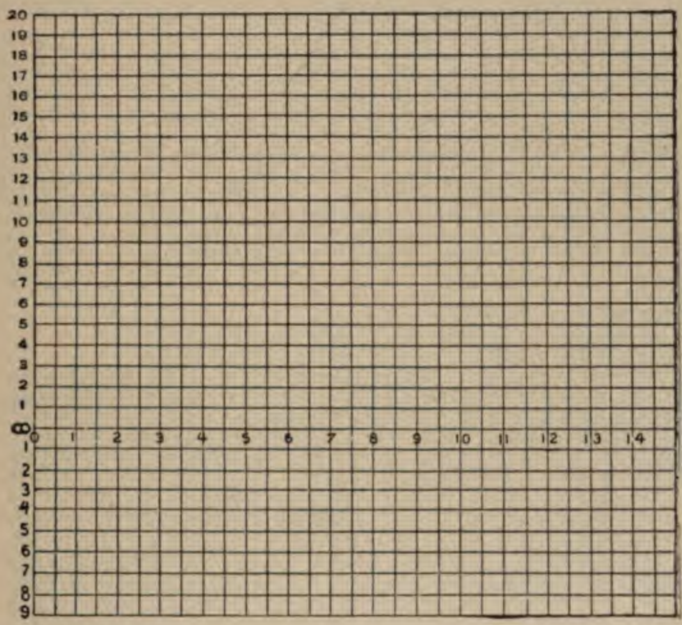


FIG. 120.—Blank on which to record the effect of a cycloplegic or myotic after the first day or first hour.

§ 7. **Physiological Effect of Atropin Sulphate in Full Doses.**—In that most interesting volume by Darwin on *Insectiverous Plants*, he mentions (p. 173) the information given to him by Donders concerning the effect upon the iris of a dog of a millionth of a grain of atropin. The fact that a naturalist of such acumen should draw his facts from the field of ophthalmology suggests, in a way, why ophthalmologists may do well to seek for other facts concerning this same class of drugs, besides those with which most practitioners are familiar. As these drugs which paralyze

the accommodation are used so frequently, it is desirable first to recall the physiological action of a full dose of one of them, —atropin sulphate, for example—if only to agree as to what the term "full dose" means. After that, we can study with advantage the effect of smaller or "minimum" doses, because later we shall wish to use these to ascertain whether they produce, on a given ciliary muscle, a reaction more or less prompt and complete than normal.

In the classical experiments made by Kuyper and Donders (B 379) with belladonna, they always spoke of it as a mydriatic, meaning that it not only dilated the pupil but paralyzed the accommodation. Since then we have a considerable number of drugs which dilate the pupil *without* affecting the accommodation—at least, in certain doses,—so that now we make a distinction between this class, the mydriatics, and the cycloplegics which do paralyze the accommodation.

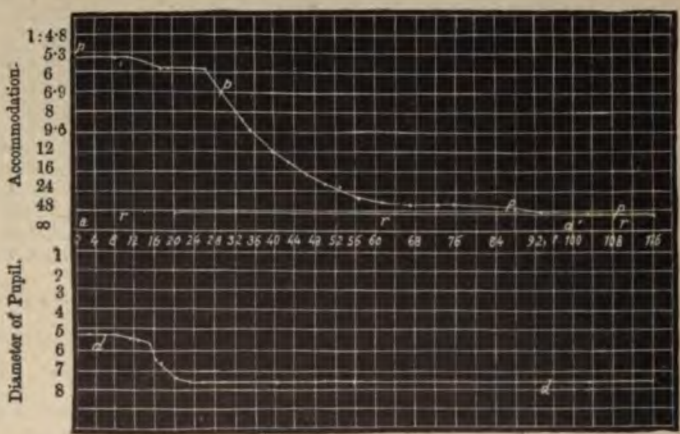


FIG. 121.—Changes in the range of acccommodation and in the diameter of the pupil after the application to the conjunctiva of "a drop" of a solution of belladonna one part to 120 (Donders).

The effect of a full dose of belladonna upon the eye has long been known. To observe its effects, let us suppose that we have a solution of one part to 120 of water (B 260, p. 584). If a single drop of this be placed on the

conjunctiva, we find that certain important changes take place in the eye, such as Donders had shown long ago. Fig. 121. In this, the numbers on the horizontal line indicate the minutes after the application has been made; those in the vertical column reading upward from infinity give the accommodation of the individual, in the inch measurement, while those reading downward show in millimeters the width of the pupil. It will be seen that in about twelve to fifteen minutes the proximate point begins to recede, and continues to do so gradually but without interruption for about an hour. At the end of that time the proximate point has reached almost its farthest limit, and at the end of ninety minutes the near point corresponds with the far point—that is, no power of accommodation remains. This condition persists for about two days. Then the effect

FIG. 122.—Changes in the range of accommodation and in the diameter of the pupil for fourteen days after the instillation of belladonna one part to 120 (Donders).

of the drug begins to disappear, and the manner in which this is done is shown in Fig. 122, also from Donders. In this, the numbers in the center represent the days after the application has been made, those in the vertical column being the same as in the previous figure. We see that between the second and the fourth day the effect lessens

decidedly. The curve which represents the proximate point rises very rapidly at first, and by the end of the fourteenth day has returned to its original position. Other phenomena are also observed in this connection. For example, a slight change may take place in the position of the far point, and it is found that convergence brings into action a certain amount of accommodative power which is not manifested when each eye is tested separately, but these matters are not of interest in this connection. Nor is the behavior of the pupil of special importance now, although we can see from these diagrams what changes that also undergoes.

The foregoing illustrations of the immediate and of the subsequent effects of a full dose of belladonna were first given about half a century ago. Since then they have been copied by Landolt, by Norris and Oliver, and in nearly all the larger text-books in different countries. In view of the fact that so many practitioners make use of solutions of atropin for this purpose day after day, it is rather

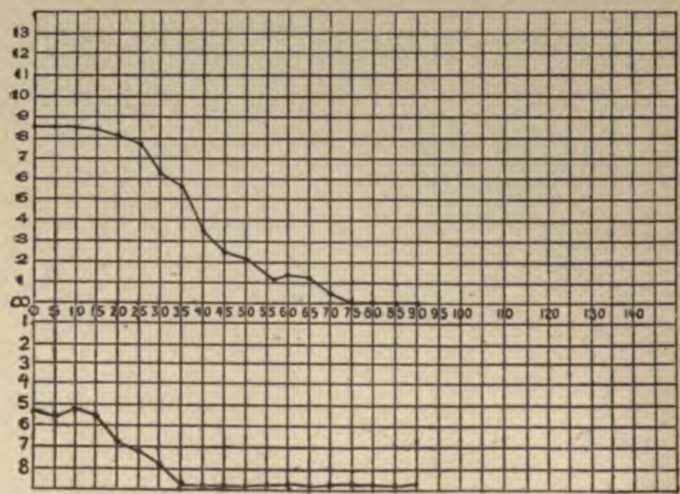


FIG. 123.—Immediate effect of a full dose of atropin.

surprising that there exist very few corroborative experiments to show the exactness of these well-known curves. In attempting to verify the measurements, it has been

very difficult or impossible to obtain curves which are as regular as those given by Donders. Especially is this the case with the weaker doses, or soon after any dose begins to have its effect. Thus, in measuring the point at which the person says he can see a given set of test types with distinctness, there is a variation sometimes at one position and sometimes at another, so that if the examiner records accurately what he finds, independently

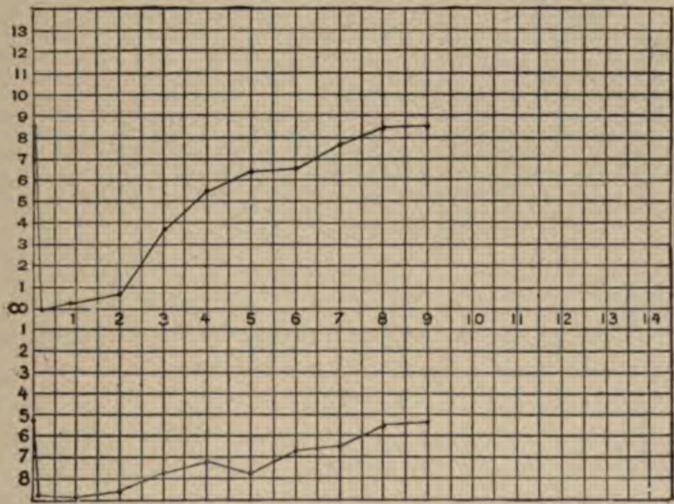


FIG. 124.—Effect for nine days after full dose of atropin.

of what he thinks he ought to find at a given time, my own trials, at least, prove that the resulting curve shows various irregularities. It appears also that Snellen had a somewhat similar experience (B 390). Figures 123 and 124 show the immediate and also the subsequent effects of 0.0001 of a gram of atropin sulphate applied to the conjunctiva. This amount of the salt is approximately the same as that contained in a "drop" of a solution of one grain to an ounce, understanding, as we should, the decided variation in the

[1] In this, and in all similar diagrams of this group, the numbers on the left, reading upward, represent diopters of accommodation, while the numbers reading downward represent millimeters to show the diameter of the pupil.

size of drops. That is, if we estimate roughly 500 drops to a fluid ounce, then each drop of such a solution would contain about $\frac{.065}{500}$ or 0.00013 gram.

It is important to observe in this connection that we obtain for the majority of eyes about the same curve, no matter whether we apply to the conjunctiva 0.0001 gram or 0.0005 gram or any dose between those limits. When the dose is rather stronger than 0.0005 gram, the curve does not drop much sooner or more rapidly, but is longer before it begins to rise. When the amount used is decidedly less than 0.0001, we find quite frequently that the curve showing changes in the accommodation drops slowly, or with irregularities, although the effect on the pupil is still quite constant. For practical purposes, therefore, we seem warranted in considering any amount between these limits as what may be called a "full dose." Several of the manufacturers prepare an ophthalmic tablet containing $\frac{1}{500}$ of a grain, and also $\frac{1}{150}$ of a grain.

§ 8. **What is the Minimum Amount of Atropin Sulphate which will Ordinarily Dilate the Pupil?**—Inasmuch as atropin acts both as a mydriatic and as a cycloplegic, and as it requires a decidedly less amount to dilate the pupil than to affect the accommodation, it is desirable to consider first the minimum dose which will act as a mydriatic, before we study the minimum amount which will paralyze the accommodation, although for clinical purposes the latter is much the more important aspect of the question.

Only a few references can be found in the literature to the minimum amount which will act as a mydriatic. Donders (B 378, p. 31) says that if a solution of 1 to 120,000 is kept "long" in contact with the cornea it will dilate the pupil. Later Feddersen (B 380) tried the effect of very weak solutions upon 76 different persons. Among these he found that when he applied to the conjunctiva enough of a solution to represent 0.000001 gram, there was mydriasis in about 42 % of these 76 persons, and when he used 0.000002 gram every pupil dilated. My own experiments on the eyes of soldiers accord fairly well with these findings.

An examination of the statements made on this subject, even by trained observers, shows that considerable confusion exists as to the use of the term "mydriasis." Some writers mean by this word a slight enlargement of the pupil and others apply it only to the maximum dilatation. We shall see later that complete dilatation of the pupil is often as difficult to obtain as is complete relaxation of the accommodation. For practical purposes, therefore, we may consider that the pupil of an adult is dilated when it measures more than seven or eight millimeters in diameter. If, therefore, we are to understand by "mydriasis" not simply the slight enlargement of the pupil, but its considerable dilatation, then apparently it is better to place the minimum amount of atropin sulphate necessary to produce this at nearer 0.000005. Even a very much smaller amount will produce marked dilatation of the pupil of a dog or other animal whose cornea is thin.

§ 9. **What is the Minimum Amount of Atropin Sulphate which will Ordinarily Relax the Accommodation?**—If the aim of the practitioner is simply to put the ciliary muscle at rest—in other words, if he only cares to determine the *refraction* of an eye, then the information which we have long possessed as to the physiological effect of a full dose is quite sufficient. But if it is desired to learn also something of the *condition of the accommodation* in a given case, he must use a small amount of the drug and then observe carefully the behavior of the ciliary muscle. When we come to deal with the pathological aspects of this study, we shall learn that an imperfect action of the ciliary muscle is one of the most frequent and important causes of muscle imbalance. Moreover, the behavior of that muscle when acted upon by small doses of atropin sulphate is often of considerable diagnostic value in showing whether there exists a tendency to excessive or to insufficient contraction.

This question as to the minimum dose of belladonna necessary to relax the accommodation of the average normal eye did not escape the notice of Kuyper (B 360, p. 587), although it is not clear how many "drops" were used. In order to obtain at least a few data bearing on the point I have used

atropin sulphate in various doses upon the eyes of thirty-one soldiers stationed at Fort Porter, Buffalo, and a few other younger persons.

The eyes of each of these men had been carefully tested on entering the service. Each had vision equal to $\frac{6}{6}$ and the ametropia present did not exceed 0.75. The men had all been practically free from asthenopic symptoms, and were otherwise in good health. At this point it is impossible to do more than to state very briefly that the results confirm in general the findings of Kuyper, and to add a summary of the observations concerning the behavior of the accommodation:

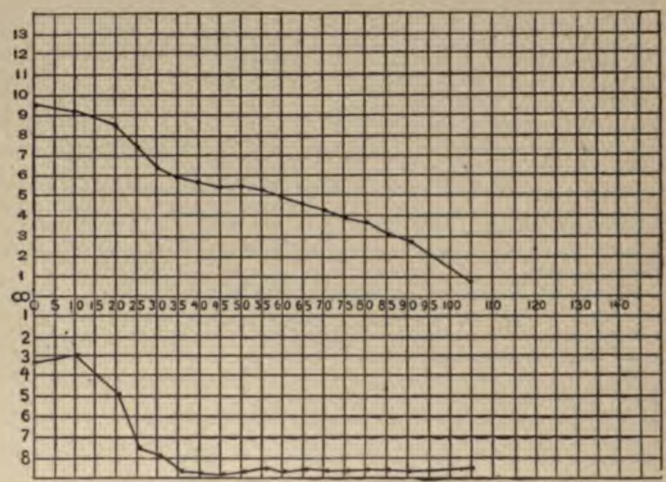


FIG. 125.—Immediate effect of a minimum dose of atropin on a young subject.

1st. When 0.000005 to 0.00001 gram (about $\frac{1}{10000}$ to $\frac{1}{5000}$ grain) of atropin sulphate is applied to the conjunctiva, it is sufficient ordinarily to produce a relaxation of the accommodation (Fig. 125).

2d. Although this relaxation begins in from 10 or 20

* Appreciation should also be expressed of the co-operation of the surgeons stationed at Fort Porter, especially Majors Halleck and Kendall. Without their good offices and their explanations to the soldiers, the men would not have offered themselves as willingly as they did, no matter what inducements were held out to them.

to 25 minutes, the full effect is not reached till more than an hour and a half after the application.

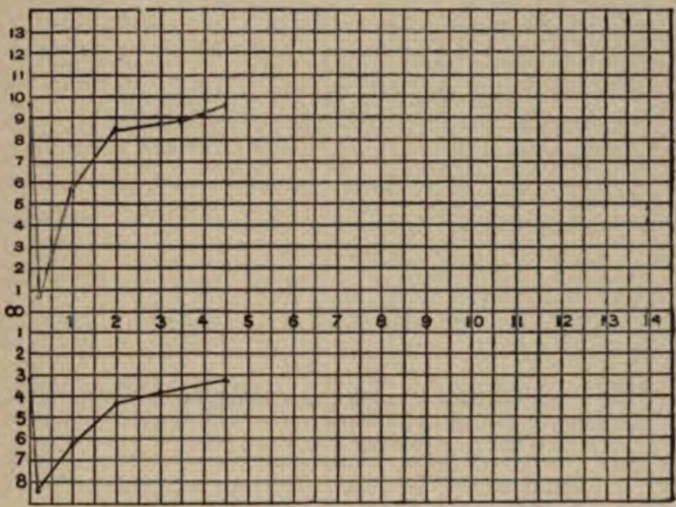


FIG. 126.—Effect four and a half days after a minimum dose of atropin.

3d. Within a few hours the effect begins to subside and has nearly disappeared by the second day.

4th. The curve representing these changes in the accommodation varies somewhat in different persons with normal eyes, this depending upon the susceptibility of the individual as a whole to the drug, and in pathological conditions upon the excessive or insufficient contraction of the ciliary muscle. Apparently the age of the individual is also a factor in determining the prompt or tardy action of this and of similar drugs, the irides of young persons seeming to respond more promptly to such stimuli than do those of middle or later life. We must conclude, therefore, that the amount mentioned may be considered, in general, the minimum dose which will produce distinct relaxation of the ciliary muscle. It happens that one or two of the manufacturers make an ophthalmic tablet containing $\frac{1}{5000}$ of a grain. One of these or a half of one therefore represents a minimum dose.

It might perhaps be asked, does this amount of atropin

sulphate produce always the curves shown above? The answer to this, as a general proposition, evidently must be in the negative. As with any amount much less than the full dose the resultant curve tends to vary from the types given, (Figs. 120 to 124), so are there many slight variations from the curve furnished by this minimum dose. Indeed, it is probable that no two eyes would give always exactly the same curve.

The individual variations in the forms of the curves may be due to two causes. One of these we call the "susceptibility" of the individual to the drug, and another depends upon the condition of the ciliary muscle of the eye itself. The real fact is, however, that when we make tests with small amounts of atropin upon normal eyes, although, as just stated, the details of these curves may vary somewhat, still, the gradual fall in the curve is so characteristic as to be recognized almost immediately.

It should be observed also that the susceptibility of the individual to the drug is in reality not a factor by any means as important as might be imagined. It is worthy of note in this connection that although some practitioners are accustomed to use strong solutions of atropin, and often very carelessly in office work, still it is quite rarely that we see the constitutional symptoms of belladonna.

§ 10. **What is the Practical Value of Minimum Doses of Atropin Sulphate?**—They assist us in deciding whether the ciliary muscle is in a normal condition or whether it relaxes more or less readily than it should. In doing this we apply a given amount to the eye and then notice what the effect is upon the accommodation, and incidentally upon the size of the pupil, observing both the time and the extent of the effect produced.

Let us suppose, for example, that we use a disc containing 0.000005 gram of atropin. The curve for this as it affects the accommodation has already been ascertained. If now we use the same upon an asthenopic eye, and find that it takes a longer time for the relaxation of the accommodation to take place that indicates that the ciliary muscle is in a state of abnormal contraction.

Or it may happen that after the application the line indicating the relaxation, instead of being a curve, seems to drop suddenly and to an unusual extent. It is then fair to infer, other things being equal, that the ciliary muscle is more easily affected than in the normal condition, unless of course the individual be unusually susceptible to belladonna.

§ 11. **The Effect of a Full Dose of Homatropin.**—It would be interesting in this connection to observe the effects of various drugs which have been used as cycloplegics, but that would necessitate too long a digression. It is worth while, however, to enquire as to the physiological effect of homatropin. This is used so constantly, especially in America, as a cycloplegic and also as a mydriatic, that we might expect to find many exact measurements had been made to determine its physiological action. Such, however, is not the case. Of the very few which are recorded, perhaps the most accurate are those of Straub (B. 397).

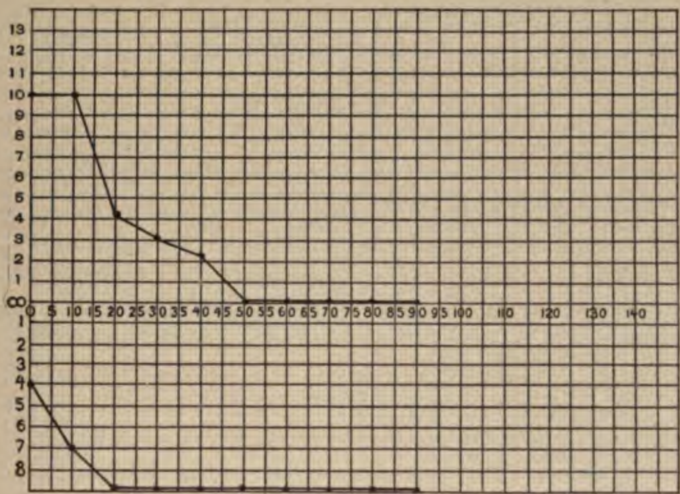


FIG. 127.—Immediate effect of a full dose of homatropin.

But, as we ordinarily employ rather larger doses of the drug for clinical purposes than he used, it seemed worth while to note the effect of these upon the normal ciliary muscle. Figure 127 shows the effect immediately after the

application of a disc containing $\frac{1}{50}$ of a grain (0.0013 gram) of homatropin hydrobromate to the eye of a boy fifteen years old. From this curve it appears that the decrease in the range of accommodation begins in about ten minutes, and it is effaced decidedly sooner than with what we may call a full dose of atropin sulphate.

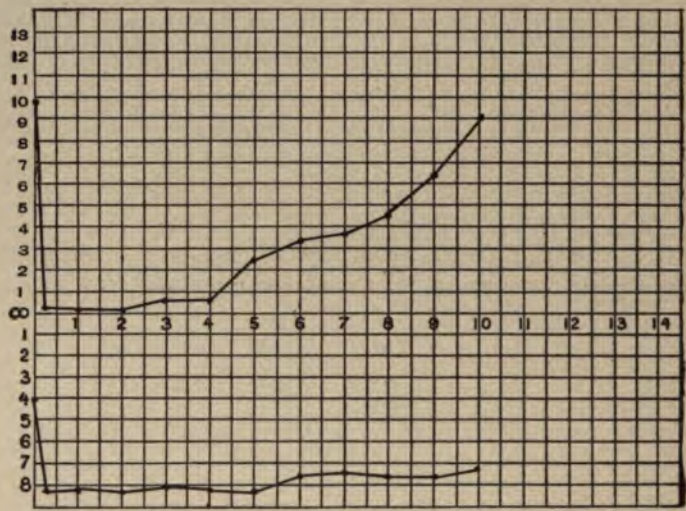


FIG. 128.—Effect ten hours after a full dose of homatropin.

But the important point is of course that complete relaxation of the accommodation lasts a comparatively short time (Fig. 128). By the end of the third hour it is again apparent, and this increases so rapidly that by the end of the tenth hour after the application has been made the normal condition in this respect is almost restored. It should be mentioned, however, that in a considerable number of individuals, after the application of the same dose, a slight imperfection in the accommodation continues even until the third or fourth day. The dilatation of the pupil keeps pace with the changes in the accommodation, as will be seen by a glance at the curves. If the dose is much smaller than this, although the accommodation may relax promptly, that effect begins to disappear almost at once.

It should be remembered that, when either atropin or

homatropin is used for clinical purposes, it is unnecessary to have the patient suffer the resulting inconvenience for as long a time as these curves would indicate. Instead of that, most practitioners then apply to the eye a small amount of eserin. We do not yet know what amount of this will counteract the effect of a given dose of atropin or homatropin. It is possible also that this double effect of drugs in an eye is a disadvantage to it. Any one who has tried this experiment on himself with rather strong doses can testify that the effect is, under some circumstances, exceedingly disagreeable. It is certain, however, that with a small dose of eserin it is possible to cut short very decidedly the effect of any of these cycloplegics, and if the dose of the myotic is small, the resulting discomfort is comparatively slight.

§ 12. **What is the Diagnostic Value of Atropin Sulphate as Compared with Homatropin Hydrobromate?**—In order to answer this question, let us understand first what the desiderata are for a cycloplegic, and then determine how well one or the other fulfils the conditions. It is generally admitted that we desire a drug—

1st. Which is safe.

2d. Which, under normal conditions, does really relax the accommodation.

3d. Whose effects last long enough to make it reasonably certain that the examination of the refraction can be made during the period of relaxation.

4th. Whose disagreeable effects pass off in the minimum time.

5th. Which is inexpensive.

1st. As to the question of safety, although atropin sulphate as used for this purpose cannot be considered dangerous, still persons who have an idiosyncrasy in this respect are met with occasionally, and its effects are then so annoying that it must be admitted that homatropin hydrobromate is preferable from this point of view.

2d. Atropin sulphate, even in minimum quantity, is apparently much more constant in its action upon normal eyes than homatropin hydrobromate.

3d. The effect of atropin persists for a much longer time

than does that of homatropin. This renders it more certain that the tests are made when the accommodation is most relaxed, provided there be no fault in the accommodation.

4th. On the other hand, atropin has the disadvantage that it gives a corresponding amount of inconvenience to the patient. When we remember, however, that the main object in the use of any such drug is usually to ascertain the condition of the refraction, it is apparently better to suffer annoyance from the drug a little longer, than run the risk of having its effect insufficient. The fact is also, as just noted, that the effects of atropin and especially of homatropin can be counteracted somewhat by the use of a small amount of eserin. When we come to consider cases in which there is abnormal contraction of the ciliary muscle, we shall see that, if any spasm be present, a dose of homatropin which will entirely relax the accommodation of the normal eye is then insufficient.

5th. As to economy, atropin sulphate is of course much the cheaper. While this is a matter of minor importance for many who come to a private office, it is not to be forgotten, especially when a drug is to be bought in considerable quantities for an institution. We may therefore conclude:

1st. To determine the refraction as accurately as is possible at a single visit, it is best to use atropin about 0.0001 to 0.00026 gram (a disc of $\frac{1}{500}$ or $\frac{1}{250}$ grain).

2d. To learn the condition of the accommodation, we should use atropin about 0.000005 to 0.00001 gram (a disc of $\frac{1}{5000}$ grain) or a corresponding part of it.

3d. When we are satisfied to know, perhaps approximately, the condition of the refraction without regard to the accommodation, about 0.0013 gram ($\frac{1}{50}$ grain) of homatropin is by far the most convenient.

4th. As a mydriatic, homatropin is infinitely the better of the two. For that purpose a disc of 0.0001 gram ($\frac{1}{500}$ grain) is usually sufficient.

§ 13. **Cocain as a Mydriatic and a Cycloplegic.**— In this connection, some mention should be made of the effect

of cocain. Its action upon the intraocular muscles has been measured by Straub (B 397, p. 216) and others, and the results are of course easily verified. Let us consider it:

(A) As a mydriatic. When about 0.0013 gram ($\frac{1}{50}$ grain) is applied to the conjunctiva, the pupil dilates within fifteen minutes, and this continues slowly for an hour. It remains at this maximum size for about half an hour, and then begins to contract. At first this contraction is quite rapid, then more gradual, and the effect disappears entirely after about twelve hours. It is interesting to notice that this dose is not sufficient to produce complete mydriasis, as the pupil still contracts somewhat in a bright light. While, therefore, cocain cannot be considered a reliable mydriatic in doses of this size, it is nevertheless very convenient when only an enlargement of the pupil is desired.

(B) As a cycloplegic. This less conspicuous action is often overlooked. A good illustration of this effect is shown in the subject of experiment by Straub. In that person, after the application of about 0.001 gram the accommodation fell from 6.5 D. to about 4.5 D. within half an hour. It remained at that point for nearly an hour and a half, and then gradually rose to its normal point at the end of six hours. While the accommodation is not always affected in this way, even by considerable doses, there is no question that this result is noticeable in certain cases. The point is, that if we use ophthalmic discs or solutions of various drugs which contain also a considerable proportion of cocain, we should remember that the cycloplegic effect may be due in part to the cocain or to the combined effect of the drugs.

(C) Mention may also be made here of the minimum amount of cocain necessary to produce complete anæsthesia, because this drug is often used in haphazard fashion and in larger quantities than is necessary. Soon after it came into use, a series of experiments made in the laboratory of the Landwirtschaftliche Hochschule in Berlin gave a numerical expression of the smallest dose which would produce the maximum amount of anæsthesia (B 400). These experiments were based on the well-known physiological fact that irritation of a sensitive nerve produces a rise in the

blood pressure practically in proportion to the degree of the irritation. Accurate measurements of the effect of an irritant (in the form of an electric current of given strength), when applied to the normal eye and also to an eye after the application of cocain in various amounts, showed that complete anæsthesia was produced in rabbits not until about fifteen minutes after the application of the full dose. This fact is of importance in connection with the effect of the drug on the intraocular muscles, and it also gives an indication as to its use in the various operations on the muscles, which will be considered later.

§ 14. **The Effect of a Full Dose of Eserin.**—Calabar bean was studied by Donders (B 260), and his curves showing the effects of what he calls "a sufficient dose" are usually given in the larger text-books. In order to verify them and

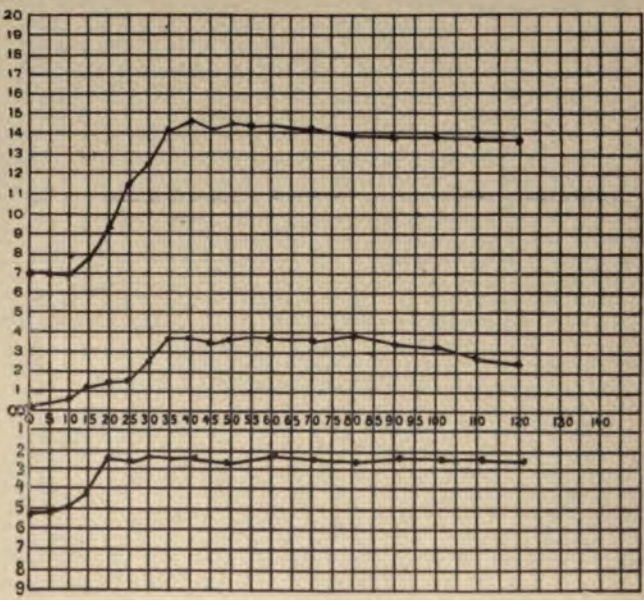


FIG. 129.—Immediate effect of a full dose of eserin.

to obtain a curve resulting from a given amount, a disc of $\frac{1}{600}$ of a grain (0.0001 gram) was applied to a normal eye. The effect is seen in Figs. 129 and 130. From these it ap-

pears that the drug affects both the near and the far point. The former commences to approach within ten to fifteen minutes after the application, and continues to come nearer

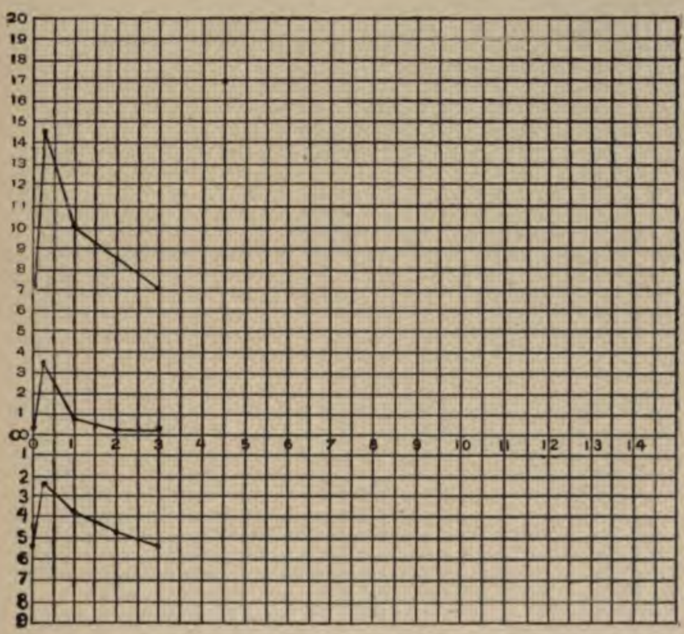


FIG. 130.—Effect three days after a full dose of eserin.

to the eye for a little over half an hour. Then, however, it recedes quite rapidly. By the end of an hour the effect has begun to subside, by the end of six hours this near point is still farther off, and the eye has resumed its normal condition toward the end of about the third day.

The far point is influenced in a similar way. It begins to approach within ten or fifteen minutes, at first quite rapidly, coming nearest to the eye in a little more than half an hour. The far point then recedes and within the first day the effect upon it has almost entirely disappeared.

The effect of a full dose of eserin upon the pupil is characteristic and is seen in the lower part of the same figures. The contraction begins about the same time that the accommodation is affected and advances constantly and

rapidly for the first fifteen to twenty minutes, reaching the maximum point usually in about half an hour. The pupil remains in that condition for about two hours, then begins to dilate, rather slowly at first. By the end of five or six hours the change is very apparent, but the pupil does not return to its original size until the expiration of the second or third day.

Although this amount of eserin produces its effect promptly and completely, it should be stated that a full dose may range from about 0.00006 to 0.0005 gram. The curve produced by one of the larger doses is similar to that just given, except that it rises a little more abruptly, and the full effect may be maintained for several days longer.

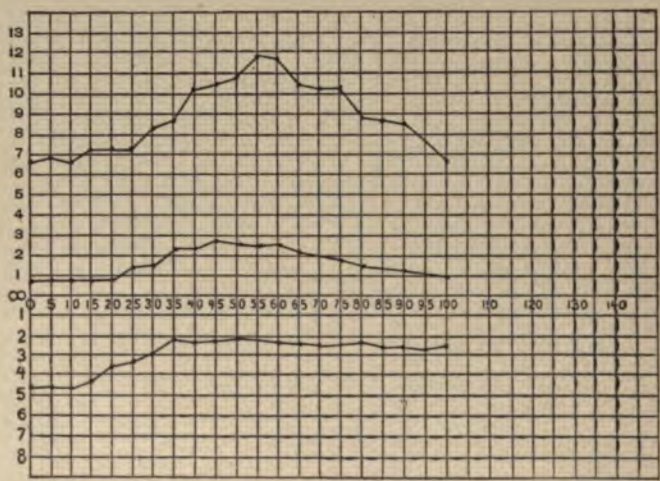


FIG. 131.—Immediate effect of a minimum dose of eserin.

§ 15. **What is the Minimum Dose of Eserin Suitable for Diagnostic Purposes?**—A considerable number of trials with weak doses of eserin have shown that for the average normal eye, about 0.000005 to 0.00001 gram is the minimum amount which can ordinarily be relied upon to produce the characteristic effect. This is in general similar to that of a full dose, except that it is rather longer before the effect is apparent and its disappearance is more rapid.

When we examine the curve more in detail we find, first,

that the near point rises with some irregularity and slowly during the first hour, and soon after reaching the maximum point begins to subside.

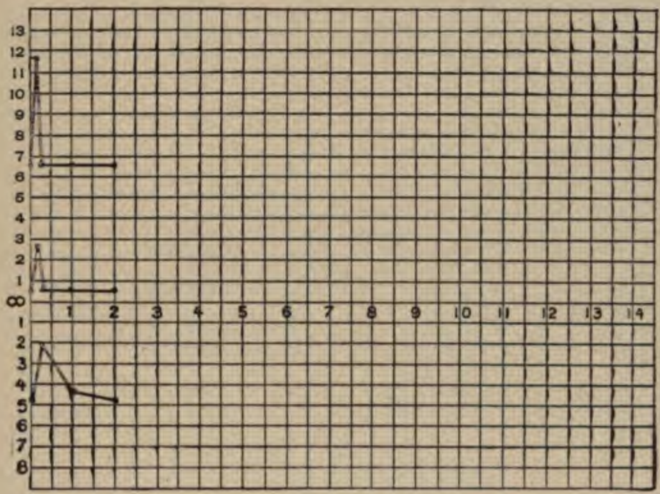


FIG. 132.—Effect two days after a minimum dose of eserin.

The far point follows, in general, the same course. Within an hour it has reached its nearest point, then it likewise begins to recede, and by the end of five or six hours is practically at the same point as before the application was made.

The effect on the pupil of this quantity is similar in character to that of a full dose, but less in degree. Contraction begins in about fifteen to twenty minutes and reaches the maximum point in ten or fifteen minutes more, and although dilatation then begins, the pupil does not return to its original size for twelve or twenty-four hours.

§ 16. **The Clinical Value of a Minimum Dose of Eserin is Similar to that of Atropin.**—When a certain amount of either is applied to the conjunctiva, we can judge at least approximately whether the effect upon the accommodation and upon the pupil is of a greater or less degree than in the normal eye. Thus a myotic may give evidence corroborating that which is furnished by the cycloplegic. References will be made to this point again in the consideration of the forms

of muscle imbalance which depend upon excessive or insufficient action of the ciliary muscle.

§ 17. **What is the Clinical Method of Determining the Effect of Minimum Doses of Cycloplegics and Myotics?**—As we should keep constantly in view the practical application of these various physiological facts, the ophthalmologist may ask how it is possible for a busy practitioner to give all the time necessary to measure the effect of any cycloplegic or myotic. Or, even if that is possible, the question also arises whether such frequent measurements are necessary for practical purposes. Fortunately a negative reply can be given to both of these questions. In rare cases where the complexity and persistence of obstinate symptoms render the utmost exactness desirable, undoubtedly it is much better to make the measurements frequently. In ordinary cases, however, that is by no means necessary. With them, after measuring the accommodation and refraction in the usual way, after determining the nearest point at which the smallest type can be seen, and after applying a disc containing a minimum dose, as already indicated, then it is sufficient in about twenty minutes to measure the near point, again in another twenty minutes a second time, and if the changes in the distance of the near point seem unusual, then after the end of a third twenty minutes still a third measurement can be made. This gives at least a general idea as to the rapidity with which the drug acts. If the blanks already mentioned are at hand, the record can be made graphically with a single mark of the pencil. Such data of course are not accurate, but they are sufficient at least to corroborate evidence obtained from other sources, and serve in part to confirm a diagnosis of insufficient or of excessive accommodation when either of these exists.

CHAPTER III.

ONE EYE IN MOTION.

§ 1. **Nomenclature.**—First, it is necessary to agree on the definition of our terms expressing motion of the globe, for different meanings have been given them by different writers. The following relate to movements of the normal as well as the abnormal eye, but the terms which describe pathological positions and movements only will be considered later.

At present we have to do with *adduction*, when the cornea is turned toward the median line; *abduction*, toward the temple; *superduction*, straight upward; *subduction*, straight downward. *Circumduction* or *cycloduction* is a form of *torsion*,—that is, a wheel-like motion of the eye around the optic or the visual axis; *intorsion* is the rotation of the upper end of the vertical axis toward the median line; *extorsion*, the rotation of the upper end of that axis toward the temple. We may have also a *true torsion*, when the globe actually makes this wheel movement, either in or out, or *false torsion*, when the wheel movement is the result of rotation about some other than the optic axis. From these nouns, verbs have been made—to adduct, to intort, to extort, etc.

A protest should be made against the use of some of these words which have been brought into our English terminology, and have no more right to existence than the barbarism "to refract," and other words of that sort. The fact is, however, that they are sanctioned by usage in this country and in England, and rather than add to the

confusion by introducing new terms it is better usually to accept the old, even if it must be done with a protest. If any change in the general nomenclature is made, it should be by the action of national or international ophthalmological societies, as Duane has suggested. Two other terms borrowed from astronomical terminology should be added to this list. They assume that the horizontal plane of the eye can be compared to the actual horizon, and the vertical meridian to that from which the degrees in longitude are reckoned, as from Greenwich. Understanding this, we may speak of *azimuth*, the distance in degrees in or out from the vertical meridian.

Plus azimuth is to the right from the center of the cornea when that is in the primary position, and *minus azimuth* to the left. *Altitude* is distance in degrees above the horizontal plane and is marked plus. *Declination* is the distance below the horizontal plane and is marked minus.

With this system, any direction from the center of the cornea can be described and located.

Thus, to indicate that the center of the cornea had been turned to the right 15 degrees and downward 20 degrees, we would write $+ 15 - 20$, the example of the astronomers being followed again in giving the azimuth first and altitude or declination afterwards. It is understood that the globe does not necessarily turn first fifteen degrees to the right and then twenty degrees down, but rotates about an oblique axis lying in Listing's plane, the center of the cornea passing from the primary position straight to the spot indicated.

§ 2. **Ophthalmotropes.**—In an article by Donders in 1870 (B 416), he says: "In spite of the fact that our knowledge of the motions of the eyes is already fairly complete, the subject remains a stumbling-block to many ophthalmologists. The literature contains many contradictions, especially in regard to the so-called wheel motion, and lecturers frequently see the earnest attempts of the listeners to obtain a clear appreciation of this mechanism end in disastrous failure. For this reason attempts have been made to produce mechanical representations which assist in giving a clear idea of the subject, and these instruments have been

called Ophthalmotropes." This statement still holds true, unfortunately, to such an extent that we also must ask what assistance ophthalmotropes give us to-day.

I. The plain rubber ball. The simplest variety of the ophthalmotrope, and one which has been invented by many a student, consists of nothing more than a rubber ball transfixed by three knitting needles representing the three principal axes,—namely, the optic, the vertical, and the transverse. This model is one of the most useful.

II. Landolt's ophthalmotrope. The rubber ball was improved by Landolt (B424) who marked upon it the vertical and horizontal meridians, and the anterior extremity of the axes of rotation of the two oblique muscles (O) and the two vertical recti (R). The circle described on the ball about the point of O, with a radius from O to the center of the cornea, would indicate, for example, the path which the center of the cornea would follow if the globe were rotated only by the oblique muscles. Or, a circle described on the ball about the point R, with a radius from R to the center of the

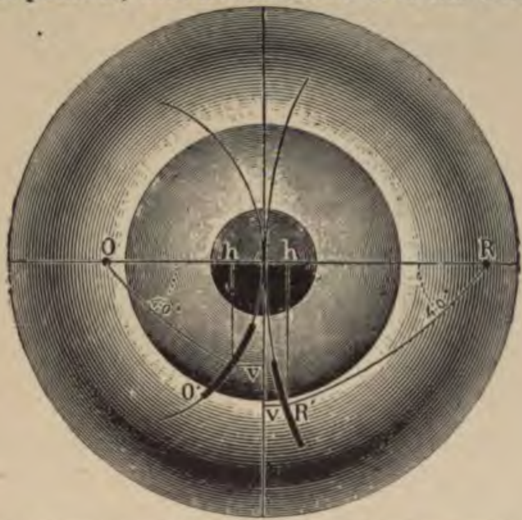


FIG. 133.—Rubber-ball ophthalmotrope with markings suggested by Landolt.

cornea, would indicate the path which the center of the cornea would follow if the globe were moved only by the superior and inferior recti. We shall see, however, that

when the globe moves from the primary to any secondary position it rotates about some axis in Listing's plane, and as the axis of rotation of the two oblique muscles, and also the axis of the superior and inferior recti do *not* lie quite in that plane, a movement about those axes can occur only under unusual circumstances. Consequently, these arcs drawn on Landolt's rubber model are apt to give rise to confusion unless this point is appreciated. (Fig. 133.)

FIG. 134.— Landolt's more complete ophthalmotrope.

Later, Landolt suggested another form of an ophthalmotrope (B 425), which, as he says, "is to demonstrate the direction and position which the eye takes under the influence of each of its muscles. A schematic eye, represented in outline merely by bands of metal for its vertical and horizontal meridians and its equator, with a cornea attached, is so arranged as to be suspended in two stationary rings, one horizontal and the other vertical, the forms of support being the rotary axes of the muscles."

The general plan of this model is shown in the illustration here given (Fig. 134).

The arrangement is ingenious and in many respects very convenient. But it has two defects. The first is that it illustrates only the rotation which takes place around the axes of the horizontal, the vertical, and the oblique pairs of muscles, and like most other ophthalmotropes, it requires the student to depend entirely on his imagination to locate the position of the retinal image.

III. Donders' ophthalmotrope. The ophthalmotrope of Donders (B 416), which has been already referred to, is quite different from those of Landolt, being constructed in the form of an eye and made to turn in a series of rings as a compass is hung in position. Apparently it is not manufactured now.

IV. Knapp's ophthalmotrope (B 257, p. 667) is seen in Fig. 135 and requires no extended description. The muscles are represented by strings, each one being attached posteriorly to a small weight. When the eye moves, it is easy to observe by the changes in position of these weights just which muscles produce that rotation.

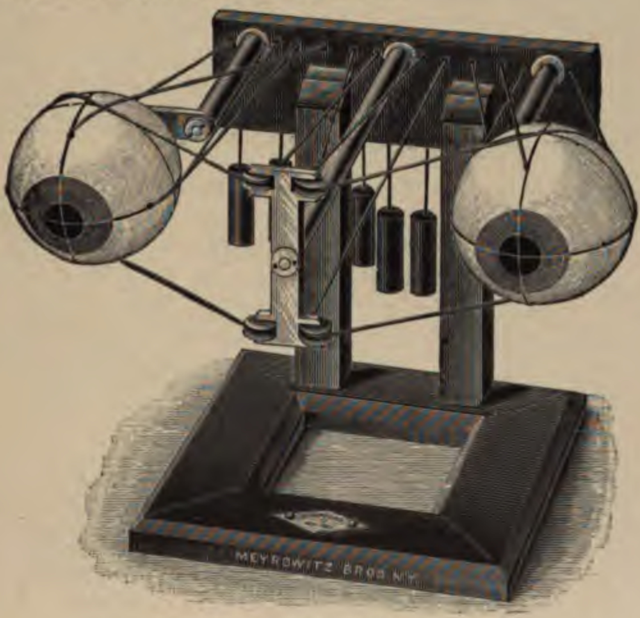


FIG. 135.—Knapp's ophthalmotrope.

V. The ophthalmotrope of the author. In as much as none of these models was quite satisfactory, it seemed worth while to construct yet another. Accordingly I have had one made such as is seen in Fig. 136. A sheet of brass 20 cm. high by 30 cm. long is perforated by two circular openings, each 6 cm. in diameter. This fixed vertical plane, or, more exactly, the flange attached to it, corresponds to Listing's

plane. Around the posterior edge of each opening there is a flange, 8 mm. thick and 12 cm. in diameter.

The edge of the flange is graduated, and is perforated by 16 tubes or canals, 4 mm. in diameter, also in Listing's plane,

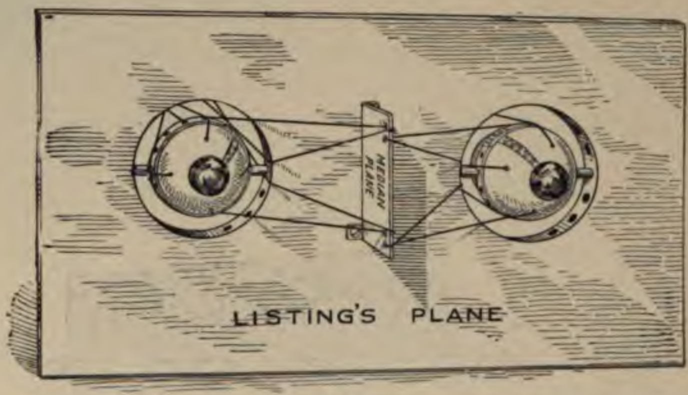


FIG. 136.—Ophthalmotrope of the author.

each being a radius from the center of the eye. They are arranged in pairs opposite each other, and if continued would constitute eight axes of the globe in Listing's plane. Into each of these canals a pin can be inserted and so held in place by a spring that it tends to press against the globe, thus holding the latter firmly in position. It is evident that any two pins which are opposite each other may suspend the globe, and that when doing so they represent an axis about which the globe may revolve in any one of eight different directions.

The part of the ophthalmotrope which represents the eye itself is a hollow globe of brass 5 cm. in diameter. It has an opening in front corresponding to the pupil, and a lens within, of sufficient strength to bring parallel rays to a focus on a disc of ground glass behind. About the equator of the globe there is a band 4 mm. wide perforated at intervals by small openings to receive the ends of the radial pins. This band is graduated, and has attached to it another graduated arc which can be slid into any position desired. The muscles are represented by strings. At proper points

these strings emerge from the interior and pass backward, to be attached to weights, as in the ophthalmotrope of Knapp.

In using this ophthalmotrope, if we wish to observe what occurs when the eye moves directly upwards, we place the two radial pins in the openings of the flange which are horizontal. As the globe moves upward it does so by rotation about an axis in Listing's plane. We can then see, by changes in the position of the weights, which muscles cause this; at the same time the degree of rotation is registered by the graduation on the vertical meridian of the globe, and the position of the retinal image on the ground glass plate can also be easily seen. If we wish to observe what occurs when the eye rotates about a vertical axis, the procedure is equally simple. Or again, we may observe what occurs when the globe revolves about an oblique axis—for example, an axis which passes from above and inward, down and outwards. To do this, two pins are passed through the openings in the flange corresponding to that position; as the globe rotates about that axis, we not only see which muscles produce that change, but we can measure the degree of the revolution by the graduation on the vertical and horizontal meridians and see on the ground-glass the position which the images occupy.

By drawing a cross with two fine lines on the ground-glass plate, it is possible when using proper test objects to see how "false" torsion is produced when the globe rotates about an oblique axis.

The advantages of this model are:

First. It represents the rotation which the globe actually makes, *that being always about an axis which lies in Listing's plane.*

Second. It shows which muscles are involved in the production of these or other rotations, as does the Knapp model.

Third. It shows the retinal image, as does the Donders model, and, besides, the relations of the two images to each other.

Fourth. It is simple and strong, and in this way adapted to the rough handling always given by students to such pieces of apparatus. This ophthalmotrope and the others

assist the teacher in conveying those fundamental ideas concerning the movements of the ocular muscles which can not be given in any other way. Also, they assist the more mature student, for no matter how large may be the experience of an ophthalmic surgeon, he is certain to have cases in which it is difficult without some such aid to form a clear mental picture of just what rotations the eye makes, or what muscles are involved and to what degree.

§ 3. **Action of a Single Muscle.**—In studying the motions of the globe, it is logical to see first how one muscle acts alone, and then in combination with other muscles. Theoretically this is very simple, for each muscle makes traction in a plane which is determined by three points—the center of motion of the globe, and the insertion and the origin of that muscle. In reality, however, the problem is not so simple. The center of motion, it is true, can be determined quite exactly, and we also know what the anatomical insertions of these muscles are. But we must distinguish between the *anatomical* and the *physiological insertion.* The latter is at the point of contact of the muscle with the globe. Now this point and the arc of contact of any individual muscle evidently change with each motion of the eye. Hence, in any calculation concerning the action of a muscle, it must be considered as if inserted at the point of contact. The third factor in this question is also a little confusing for the reason that, unfortunately for convenience of calculation, the optic foramen, with the muscles arising around it, does not lie directly behind the globe and on a level with its center, but toward the median line and partly above but principally below the horizontal plane. Thus the action of the internal rectus, for example, is not to turn the cornea straight inward, as we usually think, but, accurately stated, to turn the cornea in and a trifle downward, because the center of the origin is a little below the center of the insertion. This downward tendency must be compensated for by the superior rectus or inferior oblique. The mathematical details of this question have been worked out by several men, by Weiland (B 439) and especially by Schneller (B 438).

§ 4. **Movement in Any Direction Is a Resultant of Two or More Actions.**—Even a motion apparently so simple as the turning of the cornea straight inwards is therefore, in a strict sense, not simple, but a resultant of traction in at least two directions. Indeed, all motions are really the resultants of two or more forces acting in different directions, as when an oarsman rows across a stream the course which he traverses is a diagonal, the resultant of the forces exerted by himself and by the current.

§ 5. **The Opposing Action of Muscles.**—We have seen that the movement of the eye in any direction is a complicated action, involving the contraction of at least two or three muscles. But that is only a portion of the problem, for the lines of force which draw the globe in one direction must be accompanied by a corresponding relaxation of another group of muscles on the other side of the eye. This second group we are accustomed to call the opponents of the first group. Moreover, their relaxation must take place regularly and equally, otherwise there would be a jerking motion of the globe, or a twisting of the axis with a consequent distortion of vision. We can photograph these motions of the globe, as we shall see later, and we find that as it swings from one side to the other it does so ordinarily with a smooth and regular motion, though in certain paralytic conditions the globe wavers and halts in its course, just as we might expect when the contraction of one group of muscles and the relaxation of the opposing group are not properly co-ordinated.

§ 6. **Pre-eminent and Subsidiary Muscular Functions.**—Some writers make a marked distinction between the so-called pre-eminent or primary, and subsidiary or secondary muscular functions, and one might suspect that this was some specially characteristic function of a given muscle or group of muscles. They are, however, simply terms to express the greater or less degree of force which is exerted by a muscle or a group of muscles, as compared with another muscle or group of muscles, when both unite in producing a certain action. To return again to our oarsman, if he can row almost straight across the stream, the force

which he exerts is pre-eminent or primary; and that of the current is secondary. In other words, these terms express only the difference in degrees of force exerted.

§ 7. **Muscles which Cause Rotation in Certain Directions.**—From what has gone before, it is easy to construct a table showing which muscles are called into action in order to rotate the globe in any given direction. Such tabular arrangements are given in most of the text-books, and are usually about as follows:

UPWARD,	Superior rectus and inferior oblique.
DWNWARD,	Inferior rectus and superior oblique.
INWARD,	Internal rectus and superior and inferior recti.
OUTWARD,	External rectus and superior and inferior oblique.
UPWARD AND INWARD,	Superior rectus, internal rectus, and inferior oblique.
UPWARD AND OUTWARD,	Superior rectus, external rectus, and inferior oblique.
DOWNWARD AND INWARD,	Inferior rectus, internal rectus, and superior oblique.
DOWNWARD AND OUTWARD,	Inferior rectus, external rectus, and superior oblique.

The recti muscles tend to draw the eye into the orbit, while the oblique muscles tend to draw it out.

For physiological purposes now, and also when dealing with the diagnosis of the paralyses later, it is well to group together those muscles which turn each eye to the right and those which turn it to the left as follows:

DEXTRODUCTORS.	Right external rectus with the superior and inferior oblique.
	Left internal rectus with the superior and inferior recti.
LÆVODUCTORS	Left external rectus with the superior and inferior oblique.
	Right internal rectus with the superior and inferior recti.

DEXTRAL SUPERDUCTORS.	Right superior rectus with the external rectus and inferior oblique.
	Left superior rectus with the internal rectus and inferior oblique.
LÆVAL SUPERDUCTORS.	Left superior rectus with the external rectus and inferior oblique.
	Right superior rectus with the internal rectus and inferior oblique.
DEXTRAL SUBDUCTORS.	Right inferior rectus with the external rectus and superior oblique.
	Left inferior rectus with the internal rectus and superior oblique.
LÆVAL SUBDUCTORS.	Left inferior rectus with the external rectus and superior oblique.
	Right inferior rectus with the internal rectus and superior oblique.

§ 8. **Field of Fixation and Methods of Measuring it.**— All the points which an eye can see or "fix," while the head meanwhile remains immovable, constitute the *field of fixation* or the *motor field*. When we reach the pathological aspects of our subject, we shall find that even slight variations in the limits of this field have in some cases an important bearing on questions of diagnosis and treatment. Nearly all of the text-books point out the desirability of ascertaining the extent of these rotations, if only to recognize cases of suspected paresis, but the real fact is that such measurements are seldom made. Probably this is because the methods thus far employed are unsatisfactory. We can measure the extent of this field either subjectively or objectively.

(A) The subjective method consists in having the patient look with one eye at an object when that is moved through a given arc, in, out, up, down, or in any oblique direction. Most of the records given in the text-books were obtained in this way with the aid of the perimeter. But it is often difficult to decide whether the test object is seen directly, or with a part of the retina which is more or less eccentric. Even one who is accustomed to laboratory methods will readily make this mistake. In order to obviate that difficulty, Wood (B 456) attached on the inside of the perimeter, a

strip of paper on which words of two letters are printed. The ability to read these words when the arc is placed in different meridians indicates the extent of the rotation of the globe.

(B) The objective methods of measuring the field of fixation are, in general, the most satisfactory, although for this, suitable apparatus is required. Here again most physiologists and clinicians have depended on the perimeter.

The Perimeter.—After many trials with various forms of this instrument, I have found that the excursions of the globe can be determined most satisfactorily by attention to the following points.

First, to lessen the sources of error, the instrument as a whole should be of considerable size. One much used in this country, having a diameter of fifty-five centimeters, is none too large. It has been found that various small changes could be made in this instrument, as shown in Fig. 137.

(*a*) *The arc* should be graduated in degrees on both the in- and outside of the band for convenience in reading. At the

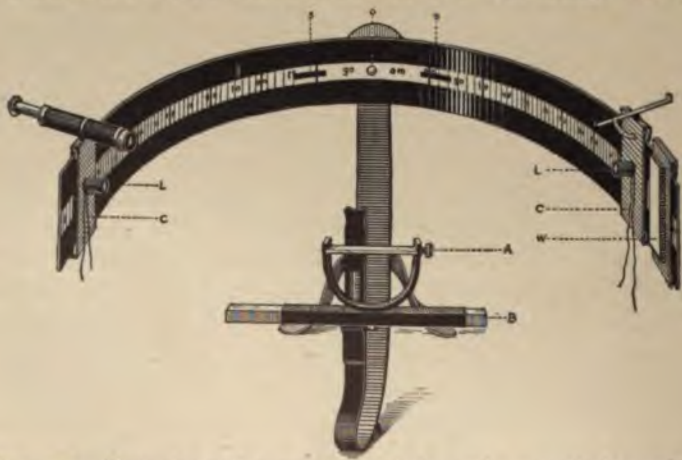


Fig. 137.—Perimeter with a gun-sight and also a telescope attachment for measuring the field of fixation.

zero point there should be an opening five or ten millimeters in diameter through which it is easy for the observer to look at the eye which is being measured. In addition, there

are two slots s s for another purpose which will be mentioned later. When centering the globe in the arc of the perimeter we have the subject look through the circular opening at the zero point, and if the eye of the observer is on the other side of this opening it is easy to see that the radius of the perimeter at that point passes also through the observed eye.

But the eye, while still in the line of that radius may be too near the perimeter or too far from it. Ordinarily we then move the head of the subject a little farther forward or backward, as the case may be, and try to sight across the arc from one of its extremities to the other, at the point marked 90°. In doing this, however, the observer is not sure that his own eye is even approximately at the extremity of the arc.

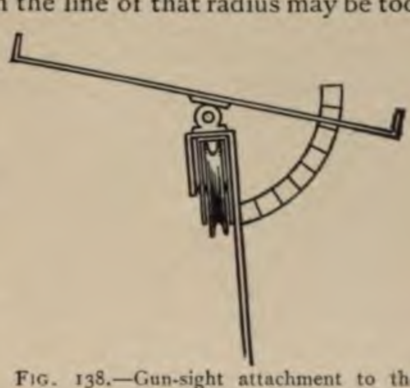


FIG. 138.—Gun-sight attachment to the perimeter to assist in bringing the center of the eye to the center of the arc.

(*b*) *Gun-sight Attachment to the Perimeter.*—In order to obtain greater accuracy in this respect, it is convenient to have a carrier or band which slides along the arc and to which a small gun-sight is attached (Fig. 138). This is nothing more than a strip of brass about five centimeters long and four millimeters wide. The ends are bent at right angles to the rest of the strip, one is filed into a point, and the other indented as a notch. The central portion of the gun-sight is fixed to the top of the carrier with a hinge, and is adjusted carefully at right angles to the arc so that wherever placed, it is in line with a radius of the perimeter at that point. There is also attached to the inner surface of the carrier a small graduated arc, its center being the same as the hinge on which the gun-sight tips. Its purpose is to mark the number of degrees which the gun-sight must be depressed in order to point at a certain portion of the globe.

While this small arc is rather convenient, it is not necessary.

After the globe has been brought into line with the radius which passes through the central point of the perimeter, the carrier containing the gun-sight is slipped on the arc and the observer sights across this at the eye of the subject. It is still impossible to know with absolute exactness that a given radius passes through the center of motion of the globe, but if the observed eye be brought to a position near the center of the arc, so that the radius marking 80 or 90 degrees on the perimeter impinges upon the observed eye just posterior to the cornea, as indicated by the gun-sight, and if, at the same time, the globe be in the line of the radius passing through the zero point, as just described, the center of motion of the globe then corresponds practically to the center of the arc of the perimeter.

(*c*) *Telescope Attachment to the Perimeter.*—While the gun-sight enables us to make more accurate observations than with the naked eye, still more constant results can be obtained in measuring the excursions of the eye by mounting a small telescope[1] on a carrier in the same way as the gun-sight—that is, exactly in the direction of a radius of the perimeter. Another carrier, weighted with a lead band must, however, then be placed on the opposite arm of the perimeter to act as a counterpoise. One great advantage of the telescope over the gun-sight is that when the eye turns outward to a point where it reaches nearly the limit of fixation, and remains there but for an instant and perhaps with a tremulous motion, we can observe its behavior through the telescope better than when simply viewing it with the naked eye.

(*d*) *Electric-Light Attachment.*—The objective examination can also be made more accurately by attaching a small electric light to the carriers. This had already been done in measuring the field of vision. When, however, such

[1] These telescopes, measuring twelve centimeters long and having a diameter of two and a half centimeters, are sold by several opticians at two or three dollars. It is necessary, however, to place in front a spherical glass of about twenty-two diopters in order to shorten the focal distance sufficiently to make them useful on the arc of a perimeter.

a light is placed just below the gun-sight or the small telescope, then as the patient's eye follows the light, the observer, looking over the gun-sight or through the telescope, sees the bright reflection just in the center of the pupil. In this way, still greater accuracy is possible in deciding how far the globe has rotated. The battery for the lamp is a small dry cell, such as is found in any of the electrical supply shops. By a spring switch, the lamp is lighted or extinguished as desired, the whole being simple and inexpensive. Of course it is unnecessary to make use of both the gun-sight and the telescope. For most purposes the former is sufficient, although it is not entirely accurate.

If we depend exclusively on either the subjective or the objective methods, errors are apt to occur. It is therefore desirable to employ both, and with a little practice the measurement can be made quickly and easily. But in spite of every precaution in the construction and use of the perimeter, it is still an imperfect instrument for measuring the excursions of the globe. As the nose projects in the median line and the brow above, and as it is impossible to sight over the arc from below upwards, the view in these directions is of course restricted. These difficulties led to the construction of the tropometer.

The Tropometer.—Many of the earlier students, appreciating the great clinical importance of the field of fixation, have made efforts to measure it otherwise than with the perimeter. As early as 1876 Nicati constructed an instrument which he called a tropometer (B 451–453), the object being to determine the excursion of the globe by measuring the tangent of the arc through which it rotated. Later Stevens (B 460) described more complicated instrument constructed on the same general principle and called by the same name. This is the one best known at present, having been figured by Maddox, De Schweinitz, and others, but ingenious contrivances for accomplishing the same purpose have been arranged by Eaton (B 461) in this country and by others elsewhere.

Stevens' tropometer (Fig. 139) consists essentially of a

head-rest of rather complicated form, and a telescope with which to view the cornea. Instead of looking directly at the eye, however, this telescope is placed at right angles to the axis of vision of the subject, and a mirror opposite the telescope at an angle of 45 degrees reflects into the telescope the image of the cornea. The best part of this instrument is a tangent scale which is placed in the eyepiece, and which shows through how many degrees a given point of the cornea—or really how far the edge of the cornea—is rotated in any direction.

After considerable experience with Stevens' tropometer, I have found that it is entirely unnecessary to turn

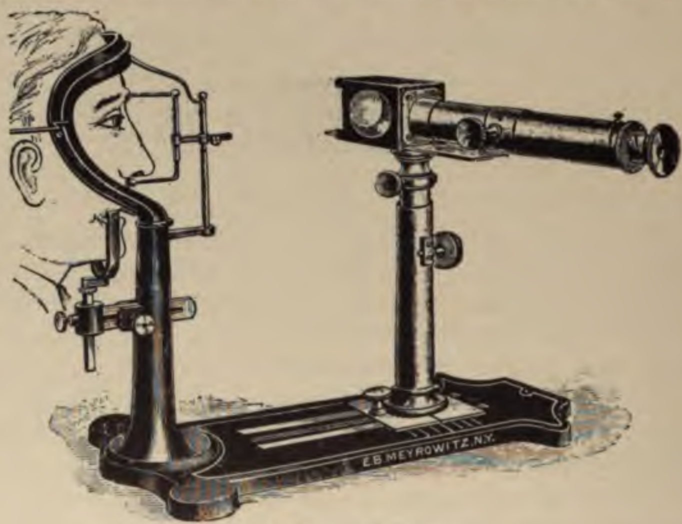


FIG. 139.—Stevens' tropometer.

the telescope at right angles to the axis of vision of the eye examined. After a time I removed the box at its distal end, and, directing the tube straight at the patient's eye, a clearer image and equally accurate measurements were obtained. Moreover, it was found that, instead of multiplying instruments, it was easy to change the ophthalmic microscope, (Fig. 117) which was used at first only for viewing the pupil, into a very excellent tropometer. This is done by placing a minus spherical in front of the object glass to

lessen the magnification, and then using an ocular which contains a tangent scale.

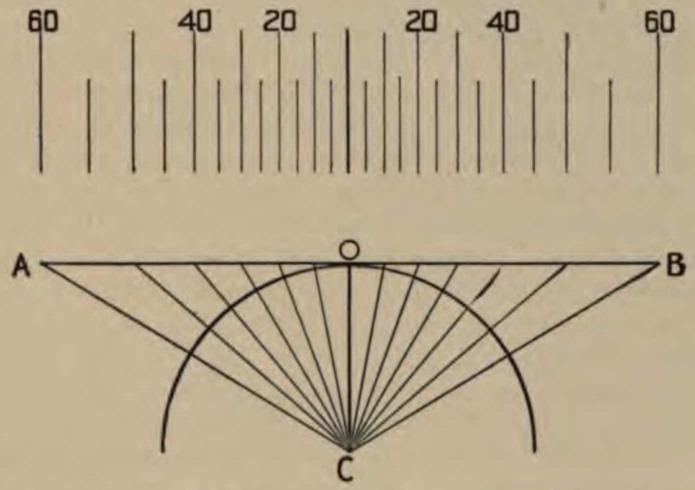


FIG. 140.—Tangent scale in the eyepiece of the tropometer. (Much enlarged.)

For those who have forgotten the exact meaning of this term, the accompanying diagram (Fig. 140) may be of some assistance. Thus, if different radii be drawn from the point C, at intervals of say ten degrees each, to the line AB, which is tangent to the arc at the point O, then the points at which these radii intersect the tangent AB would mark off what we may call a "tangent scale." Instead of drawing this one line horizontally across the field of the instrument it is better for our purpose to have a number of parallel lines whose distances from each other are the same as the distances at which the different radii intersect the tangent already referred to. Theoretically it would be quite sufficient to have a single tangent scale stretching across the field. In practice, however, it is sometimes more convenient to have two such scales. One of these, numbered from right to left, measures the rotations of the globe in one direction, and another scale, numbered from left to right, measures the rotations in the other direction. To use this form of the tropometer, it is only necessary to turn the instrument on its vertical axis until the zero point of the scale touches the

edge of the cornea. Then observe through how many divisions of the scale that point on the cornea moves when the eye is rotated in a given direction, and we have at once that rotation in degrees. If it is desired to measure the excursion of the eye up or down, we turn the eyepiece so that the scale is vertical, and have the lid of the eye which is under examination lifted so that the edge of the cornea is distinctly visible. The rotations of the globe up and down are then observed in the same way as when in the horizontal plane.

When the ophthalmic microscope is thus changed into a tropometer, the subject, sitting in front of the instrument, ordinarily steadies the head by resting his elbows on the table, and supporting his chin on the palms of his hands. That is usually sufficient for clinical purposes. For laboratory work, however, or when special exactness is desired, it is well to use the head-rest already described (Fig. 117).

§ 9. **Extent of the Field of Fixation.**—The limits of this field, as found by earlier students of the subject, are shown in the following table taken mainly from Landolt and Eperon.

	Schuurmann,	Volkmann,	Hering,	Kuster,	Schneller,	Landolt,	Duane.
Abduction	42	38	43	43	46–54	46	53
Adduction	45	42	44	45	52–56	44	51
Superduction	34	35	20	33	——	44	43
Subduction	57	50	62	44	——	50	63

The field of fixation as shown by Schuurmann and Landolt is seen in Fig. 141 and Fig. 142.

The difficulties of ascertaining the exact limits of the field of fixation are shown by Duane. He gives the results of the several measurements made on the same individual, and his figures prove what can be easily verified, that it seldom happens that any two tests agree exactly in all their details.

In other words, we know quite nearly what the field of fixation is, though it is evidently impossible to select any special number of degrees which shall mark the limit of motion in a given direction in any individual case.

It is important to remember that the limits of the field of

fixation are not to be judged entirely by the number of degrees which an eye can turn in any given direction. Much also depends upon the *manner* in which that motion is made. In some individuals, when the group of muscles under examination is strong, the eye will turn without hesitation to a certain point on the arc of the perimeter which is the limit of motion in that direction, and the globe can be held in that position steadily and without effort for several seconds. On the other hand, when this group of muscles is weak and the eye approaches the limit of fixation, it does so in a halting and almost tremulous fashion.

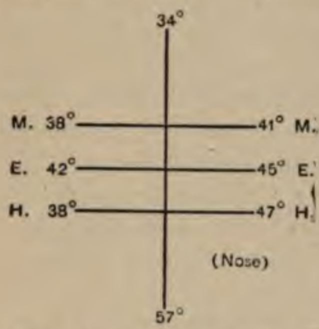


FIG. 141.—Limits of field of fixation in myopia, emmetropia, and hypermetropia (Schuurmann).

It remains at that point only an instant, and at once swings back into a more usual position. The *behavior* under such circumstances is most important from the clinical standpoint in showing not simply the limit of the excursions, but also the ability to reach it. This fact will be referred to more than once when this subject is studied from the clinical aspect.

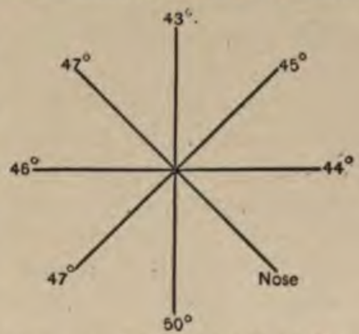


FIG. 142.—Limits of field of fixation (Landolt).

§ 10. **Of what Clinical Value is a Knowledge of the Field of Fixation?**—After devoting so much time to the discussion of instruments for measuring the field of fixation and to the results obtained by them, we naturally ask—what of it? In order to answer this, let us presuppose for a moment an acquaintance with the pathological aspects of our study and recall the points which we desire to learn in any case of heterotropia,—as, for

example, in an abnormal convergence. We wish to know:

1st. Does any deviation of one eye or both exist?

2d. Which eye—if either—is especially affected?

3d. Exactly which muscle or group of muscles is affected?

4th. Is the deviation due to excessive contraction of the adductors (active esotropia), or to paresis of the abductors (passive esotropia), or is it due to both causes?

Some practitioners, it is true, do not take the time and trouble to ask these questions. For them it is sufficient to know that a deviation does exist; they recognize only the more evident forms, and usually make some operation promptly for all varieties. Such criminal carelessness requires no comment.

But when an attempt is made to answer any of these questions too much dependence is often placed on the tests with double images, such as will be considered in the part relating to paralyses. But such tests, like subjective tests with the perimeter or with any similar instrument, have two important defects. They presuppose sufficient vision in each eye to recognize the test objects, and also sufficient intelligence in the subject for exact replies. Now the fact is, that many of our cases are deficient in one or both of these qualifications—for example, most children, or uneducated adults, especially those of dispensary or hospital practice, and others unnecessary to specify here. Moreover, in all subjective tests, no matter how good the vision or how intelligent the patient may be, still another element, the personal equation, must be taken into account. Evidently, therefore, if we would obtain more than the most superficial knowledge of these important deviations, we must collect all the data we can by objective measurements. This applies not simply to the limits of the field of fixation, but to the rapidity with which the globe swings from side to side, to the lifting power of the adductors, and possibly also to the muscle sound—all of which are to be considered presently.

Having thus glanced at the reasons why the objective methods of examination are preferable to the subjective, let us ask more exactly in what way the measurements of

the field of fixation enable us to answer one or more of the four questions already referred to.

1st. As to determining whether or not a deviation does exist. When that is not always apparent (heterotropia) but usually latent (heterophoria), the contraction or extension of this field may alone indicate the deviation. That may not be shown entirely by the limits of the field, but quite as much by the *behavior of the eye* as it approaches those limits, as already indicated. In this connection it is only possible to refer briefly to this diagnostic point.

2d. Any difference between the limits of the field of fixation in one eye as compared with the limits in the other eye, undoubtedly does assist very materially in the conclusions. Most of the tests with double images, especially those for determining the static position of the globe, do not show conclusively, and sometimes not at all, in which eye the difficulty lies. On the other hand, any one accustomed to make measurements of the field of fixation of each eye, will appreciate that in a considerable percentage of cases heterotropia is accompanied by a limitation of the field in one eye entirely, or at least in one as compared with the other.

3d. Almost as a corollary from the last statement, it follows that the limits of this field assist in locating the group of muscles, or even the principal muscle affected.

4th. Finally, in cases of heterotropia the question always arises, does the eye before us deviate because it is drawn out of place by excessive traction of one group of muscles, or because of imperfect innervation of the opposing group? This question is so difficult to decide that we need the help of all the methods of investigation at our command. And in this, measurements of the field of fixation apparently do assist, at least to some extent. For, in a given case of esotropia, if the eye can be turned outward the usual amount, or even more, then we are safe in assuming that the abductors have quite a sufficient innervation, and probably the esotropia is due to excessive action of the adductors. It must be understood, of course, that such evidence of itself would be unreliable, but when that is corroborated by other

data, the conclusion is at least more warrantable than without such evidence.

§ 11. **Lifting Power of the Adductors.**—Having ascertained by what muscles the eye is rotated in a given direction and also the limits of that rotation, we may ask next what amount of force they actually exert, or what is their lifting power. An attempt has been made to determine this.

FIG. 143.—Arrangement for measuring the lifting power of the adductors.

The method is shown in Fig. 143. The eye being under cocain, a speculum is introduced, and a pair of small forceps made especially for this purpose is fastened to the conjunctiva over the insertion of the external rectus, grasping firmly also the tendon of that muscle. The thread which is attached to the forceps is made to run obliquely backward over a roller and is connected below with an open dish. Water is then injected into the dish from a small syringe until the eye begins to move outward. By slightly decreasing or increasing the amount of water in the dish, it is possible to reach with considerable exactness a point where the cornea is just held in position. Then, weighing the dish with its contents, we have quite nearly the lifting power of these muscles. It is not easy at first to decide exactly what weight can thus be sustained by the adductors, for when the limit is nearly reached, each addition to the weight causes the globe to yield sud-

denly, although it tends at once to resume its former position. With a little practice, however, one can determine quite well how many grams can thus be sustained. If greater exactness is desired, it can be obtained by viewing the edge of the cornea through the ophthalmic microscope fitted with a tangent scale. This, however, is too cumbersome for clinical purposes.

The results of these measurements, briefly stated, are as follows. When a person looks at an object directly in front, the force exerted, expressed in weight, ranges apparently from ten to eighteen grams, with an average of about fourteen grams. It is quite probable that these figures will need revision when measurements have been made of a larger number of normal eyes. For although these are evidently the most desirable for such experiments, it is difficult to find subjects who will submit to the inconvenience. The question is an interesting one, and apparently the results are of some importance clinically. In a case of esotropia, for example, the lifting power of the adductors constitutes at least corroborative testimony in deciding the question whether the eye tends to turn in from excessive action of the adductors or from insufficient action of the abductors. On this question depend to a certain extent the diagnosis and the form of treatment—certainly if that be of an operative nature. It helps us to decide whether to make advancement of the externus or tenotomy of the internus.

§ 12. **Tensile Strength of the Recti.**—The power of the adductors to lift a given number of grams should not be confused with what may be called the tensile strength—that is, the weight which a muscle will sustain without breaking. Dianoux (B 464) gave this, in dogs, as about five kilos. As that seemed rather large, a few simple tests were made with the recti and with other muscle tissue. These were interesting and can be easily repeated. If a piece of beef be cut parallel with its fibers, trimmed so that it is the size of an internal rectus, and suspended with a weight attached to the lower end, it will break promptly when the weight reaches about one and a half kilos. Therefore it was supposed that the recti might also break with an equally light

weight. But that is not the case, perhaps because of the abundance of fibrous tissue of which they are composed. For example, one end of an internal rectus was attached to a rod, while the lower end, having a clamp attached to it, held a small pan, into which weights could be placed. It was found that the muscle would suspend easily a weight of from two to two and a quarter kilos before breaking.

In this experiment, if the muscle is tied, the cords, which hold it above and below, are apt to slip from the ends before the fibers break, and only with special care can this be avoided.[1] It will be noticed that the sustaining power of a rectus muscle, determined in this way, although several times greater than that of ordinary muscle fiber, is still decidedly less than the five kilos which are given by Dianoux as the tensile strength of the recti. This difference may be due to the freshness of the material used or to the method of conducting the experiment. The fact is, however, that, in certain persons at least, the tensile power of the recti is by no means as great as has been generally supposed. The clinical bearing of this will be appreciated later in connection with one or two operations upon those muscles. Thus we shall see that in the so-called Panas operation for tenotomy, a hook is passed under the insertion, and the globe is rotated far toward the opposite side. In this forcible stretching of the muscles there is evidently real danger of their rupture.

§ 13. **How can the Rapidity of the Lateral Motion of the Eye be Measured?**—We are indebted to Volkmann (B 466, p. 275) for the first attempt to measure the rapidity with which the eye moves from side to side. He directed the individual to look quickly from right to left and took the average time required for a single movement. Helmholtz's plan (B 257) was to have the person count the number of electric flashes which could be perceived while the eye was passing from one point to the other. But these methods gave varying and rather unsatisfactory results.

[1] Acknowledgment should be made to Mr. H. H. Buckman, Jr., for his assistance in making these measurements of the tensile strength.

More recently, Dodge (B 468) measured the rate of movement by the aid of photography. This was a step in advance. His method was to throw a beam of light upon the cornea and have it reflected into a camera. The plate-holder of the latter contained a narrow horizontal slot behind which a glass negative was made to fall. This plate-holder, which Dodge mentions as an important part of his apparatus, was a

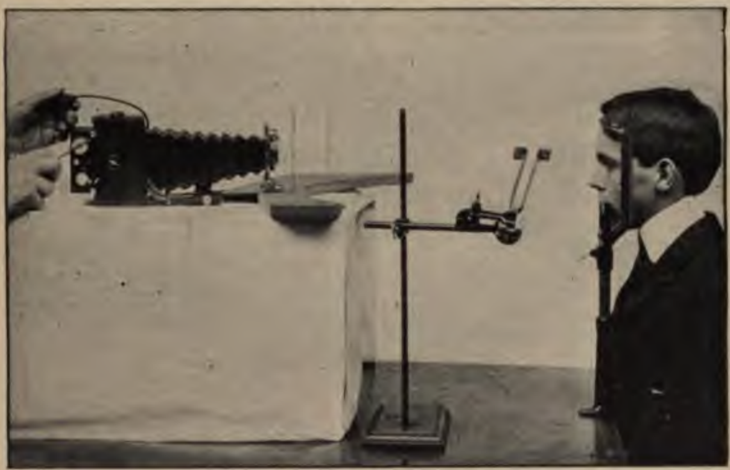


FIG. 144.—Arrangement for photographing by daylight the time required for an eye to swing through a given arc.

complicated affair, containing a small tank of oil through which a piston passed to regulate the time of the fall of the plate. It seemed therefore that if these measurements could be simplified and adapted to hospital or possibly to office work, by showing when an eye moved most rapidly and therefore most easily in one direction or the other, they might thus give valuable hints, at least, as to the condition of the muscles.

Accordingly, the following arrangement for photographing with daylight the rapidity of the lateral motion was devised (Fig. 144).

First. The head-rest. This has already been described. It was screwed firmly upon the end of the table opposite to the source of light, and by changes in the adjustment the position of the head could be altered as desired.

Second. The camera. For the earlier experiments[1] the camera used was the Eastman plate camera No. 3. The only alteration in this was the cutting of a horizontal slot about two millimeters wide across the center of the thin hard-rubber slide in front of the film. The latter came from the manufacturer on one roll, arranged to unwind upon another roll by means of a small crank moved by hand. In spite of this crude method, with a little experience that camera gave excellent results. It can be improvised without difficulty. In later measurements, trials were made of the Century camera, attaching to it the same roll-holder used with the first instrument. The roll was then turned by a small electric motor, also attached to the back and connected to the roll-holder by a simple gearing. The power consisted of three dry cells of the United States Company, No. 3. The substitution of a motor for hand power was a gain in one respect, the resulting picture being much more uniform. It had the disadvantage, however, of requiring still another piece of machinery, and the inevitable jarring produced a wavy effect in the picture.

Third. Time record. To obtain this a small mirror was at first placed outside the window. That reflected a beam of light upon the tip of a tuning-fork, which was constructed to make fifty vibrations in a second. By properly adjusting the position of the tuning-fork, the ray of light was reflected into the camera in such a manner that it fell upon the horizontal slot in the rubber slide, which was in front of the film. In the later experiments electric illumination was substituted for daylight. One of the so-called Adams-Stagnal arc lamps was placed in circuit on the ordinary alternating 104-volt current, and had the great advantage over sunlight that it was available at any time. This arrangement is shown in Fig. 145.

Fourth. Arc of rotation. In order to determine the distance in degrees traversed by the eye, an arc was drawn on the table a certain distance in front of the eye, and

[1] In referring to these experiments, acknowledgment should be made of the faithful assistance rendered by Mr. Lionel Duschak, later of the Department of Chemistry at the University of Michigan.

at points in this arc, as desired, two knitting-needles were placed, to each of which was attached a piece of paper or other object suitable for fixation. When the person looked from one of the knitting-needles to the other, the eye would of course swing through an arc of known length.

FIG. 145.—Arrangement for photographing by electric light the time required for an eye to swing through a given arc.

Finally, it was found convenient to have the whole arrangement on a table about five feet high, to obviate the necessity of constant stooping.

The manner of making the exposures, while simple in principle, requires attention to several details. The subject's face is so lighted that the reflection from the cornea enters the camera, and is focused about the center of the slot covering the film. When ready for an exposure, the person under examination is told to look as rapidly as possible from one of the knitting-needles to the other, the tuning-fork is plucked and the roller turned, either by hand, or by opening the current which turns the rolls. The resulting photographs are easily understood (Fig. 146).

When the eye and the film are both at rest, the ray of light, reflected from the cornea through the slit, is focused on the film as a bright spot. When the film is stationary and the eye turns from side to side, the bright spot, moving along the horizontal slit, describes a horizontal line on the film. When the eye is stationary and the film is made to move vertically on the roller, the point of light describes a

FIG. 146.—Photographic record of the time required for an eye to swing through a given arc. The line on the left, which is oblique at intervals, is caused by the reflection from a point on the cornea. The toothed line on the right is the reflection from a tuning-fork, whose rate of vibration is known. The number of vibrations between the beginning and the end of any oblique portion of the broken line, shows the time required for the eye to swing from side to side.

It will be noticed that the film moved more rapidly at one time than at another, this being due to the fact that it was unrolled by hand.

vertical line. When, however, the eye, with the reflection from it, moves horizontally, and at the same time the film moves vertically, then the spot of light describes an oblique line. The length of this oblique line is therefore the measure of the time required for the eye to swing from one side to the other.

When the results obtained in the manner indicated are compared with those reported by Dodge, they are very nearly the same. The differences are probably accounted for by the fact that his measurements were based on the supposition that the movement of the cornea was the same as that of the spot of light reflected from it. But allowing for this, the results are quite as constant as could be expected, and show that, even with the small camera containing a film moved by hand, it is possible to measure the rate and character of the lateral movements of the eye with a considerable degree of accuracy. Photographs made in this way have also been called *photograms* or *kinetograms*. When attempting to read their meaning, a superficial glance is often deceptive. As the simplest and best method, practically, to move the film on the roller is by means of a hand crank, and as this movement of the hand naturally varies in speed from one instant to the other, the rate of motion of even a normal eye moving with perfect regularity may appear quite irregular when that motion is depicted on a film which moves irregularly. This is indicated, of course, by the vibrations of the tuning-fork being spread out in some places and crowded together in others.

As to the result of these measurements, it must be admitted that they are not constant for small arcs — from five to fifteen degrees — and although these are given by Dodge as being thirty thousandths of a second for a swing through an arc of about five degrees, and about forty thousandths of a second through an arc of ten degrees, my own results with such small distances are too irregular to warrant any statements on that point. When, however, we measure the swing through an arc of twenty to thirty degrees, the results are more constant. It may be stated in general that the eye requires fifty to sixty thousandths of a

second to swing through an arc of twenty degrees, about seventy-five thousandths to swing through an arc of thirty degrees, and about one hundred thousandths, or one tenth of a second, to swing through an arc of forty degrees.

A word should be added concerning the individual character of these photograms or kinetograms. The figures obtained from different tests indicate that the time required for the eye to swing through a given arc differs somewhat in different persons. It is quite noticeable, though, that a certain form of photograms is repeated by the same individual, indicating that the eye has apparently a lateral swing which is, to a certain extent, characteristic. Its behavior during the period of rest between its swings is also apt to be characteristic. In some persons it remains entirely at rest at the end of the arc of rotation, while again, especially in cases of paresis, it remains at the halting point trembling, as it were, in its place, or it may begin almost at once to move back to the other end of the arc.

What is the clinical value of a knowledge of the rapidity of the lateral motion? So little is known of this subject that any statements as to its value must be made with caution. Such facts as we have, however, constitute corroborative evidence of still a different kind as to whether the action of a given set of muscles is or is not entirely normal. Thus, when a question arises whether an abnormal convergence is due to a contraction of the adductors, or to an impaired innervation of the abductors, if the eye swings toward the median line much more rapidly than in the normal condition, it is probable that the adductors are abnormally strong. On the other hand, if the swing inward is at what may be called a normal rate, or certainly if that movement inward is less rapid than normal, we may incline to the opinion that the difficulty is due rather to a relaxation of the abductors. Of course it would be impossible to base a diagnosis on such evidence alone, but these data, with those obtained by other methods of measurements, may furnish the basis for a valid conclusion.

§ 14. **Movement of the Eye while Reading.**—Measurements made by other methods have shown long ago

that as the eye passes along a line from left to right, in the act of reading, it stops usually four or five times for perhaps five or ten thousandths of a second. This is apparently in order that the brain may receive the impression made upon the retina. At the end of the line, the eye rests for a varying length of time, then swings back to the left side of the page and begins the same journey again. It is not difficult to measure, with the apparatus referred to, the rapidity with which an eye thus moves. Such a reading record or photogram is seen in Figure 147. These records are of interest in showing the really complicated nature of an act apparently so simple as that of reading. The more closely this act is studied, especially by these photograms, the more readily can we understand how it may become difficult or

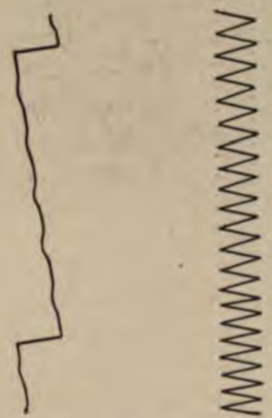


FIG. 147.—Drawing from a photograph of an eye in the act of reading. The zig-zag line on the right shows the vibrations of a tuning-fork.

painful when there exists any defect in either accommodation or convergence.

Dodge (B 449) says that when the eyes turn from side to side, in looking at distant objects, especially when such objects are moving, occasional halts are also made by the eyes as in the act of reading. Indeed, there seem to be five and possibly more kinds of lateral movements which can be distinguished by these photographic measurements.

§ 15. **Measurement of the Act of Winking.**—As the orbicularis palpebrarum is, in a certain way, intimately connected with the ocular muscles, we should notice in passing those rapid contractions of its central fibers which constitute the act of winking. The method of measuring by photography the time occupied in the act of winking is similar in every way to that by which we measure the length of the time required for the eye to swing from one side to the other. The arrangement of the light, the position of the eye and the camera, are all practically the same. The ray of light which is reflected from the cornea passes through the camera and through the small horizontal slit in the slide

FIG. 148.—Corneal reflection broken by a wink of the subject.

before the film. The film is then moved vertically by turning the crank. The ray of light thus reflected on the cornea of course describes a vertical line. But if the lid is closed, as in the act of winking, then, the cornea being covered, the line showing the reflex from it is of course also interrupted. The length of time which that interruption occupies is shown at once by the vibrations of a tuning-fork whose rate is known, and which also reflects a ray of light through the same slit upon the side of the same film. This is seen in Fig. 148. These photograms show that the act of winking requires, from first to last, in the average individual, about one half of a second. It may be divided into three portions.

First, the time occupied in the closure of the lids. This is a sudden movement, and the picture shows that the line is suddenly broken off at this point. That part of the act

requires from about one tenth to one twentieth of a second.

Second, the time during which the lid remains closed. This also varies, in different individuals, but is usually about two to three tenths of a second.

Third, the time occupied in raising the lid. This part of the act is by no means as rapid as the first; that is, the lid is raised much more slowly than it is closed, occupying from one to two tenths of a second, or even longer.

It may be asked of what use is the measurement of the act of winking? When it is decidedly slower in one eye than in the other, that fact may be of real clinical value, as showing that the corresponding branch of the third nerve is partly paralyzed. It may be the first indication of a nuclear paralysis. That symptom alone, or with others, may point to the location of an existing brain lesion.

§ 16. **A Wheel Motion (True Torsion) Possible with One Eye.**—Thus far we have been considering the rotation of one eye about some axis which is perpendicular to the antero-posterior axis. It is possible, however, for a rotation to be made about this axis, as a wheel turns on its axle. There has been much discussion as to whether such a rotation of the globe is possible with one eye, but the point was settled by Javal (B 264, p. 298), who showed beyond doubt that when, in viewing a distant object, he tipped the head toward one side, a cylindrical glass no longer gave the proper correction, as the upper end of the vertical axis of the eye did not tip outward as far as did the glasses.

Very recently this subject has been carefully studied again from other standpoints, and although new light has been thrown upon the various factors which modify this form of torsion of one eye, the underlying facts remain the same. While it is interesting to know that it is possible for one eye alone thus to make a true wheel motion about the antero-posterior axis, that form of monocular torsion is so unusual as to be of no practical importance, and may therefore be left with this brief mention.

§ 17. **Sound Produced by the Eye Muscles.**—Maddox begins his book on the ocular muscles by remarking on their silence, and in doing so reflects the popular impression. But

more than a quarter of a century ago Hering (B 480) called attention to the fact that their motion, especially in convergence, produces a rustling sound, which could be heard when listened to properly. Hering says: "The change in the character of the eye sound in convergence is so distinct as to be recognized at once. I have asked several observers who were especially proficient in auscultation . . . to listen while I made the experiment, and they have at once been able to decide entirely by means of the change of the sound whether or not my eye was looking in the distance, or was converged for a near point."

That observation has lain buried in the literature all these years, and yet possibly it may have a little practical value. Some of these sounds are not difficult to perceive, especially with a proper stethoscope and with patience in accustoming the ear to them, but after a considerable number of trials I must confess that I am not able to recognize them with the confidence expressed by Hering and his medical friends.

Thus if the lids be closed forcibly, most persons can recognize subjectively a faint rustling sound. It can be distinguished objectively by placing on the eye or the edge of the orbit a small cone of hard rubber—an ear speculum, for example—and connecting this by means of a rubber tube with the ear of the listener, though I have found that the muscle sound could be recognized more easily by listening to it with a modified form of the double stethoscope (Fig. 149).

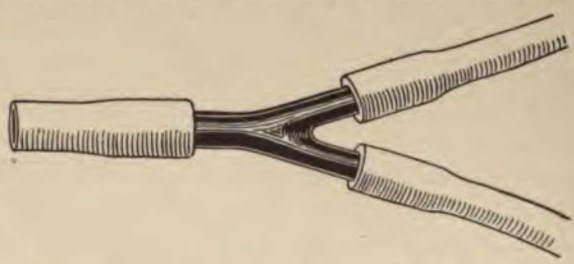


FIG. 149.—Stethoscope for the recognition of muscle sound.

This art must be learned, just as with the use of the stethoscope for detecting delicate variations in the sounds of the

lungs or heart. It is true that if the stethoscope be placed elsewhere, as over the thick part of the corrugator supercilii, and that muscle be strongly contracted, it is also possible to perceive a rustle, apparently different from the rustle heard over the orbit. In the present state of our knowledge it can only be asserted that the motions of the ocular muscles can be heard, and that differences in their sound can be distinguished, but we have yet much to learn concerning the relation of these sounds to imperfect muscular action, or if they have any clinical value.

CHAPTER IV.

BOTH EYES AT REST.

DIVISION I.

General Considerations.

§ 1. **Both Eyes at Rest.**—All that has been said thus far pertains or may pertain to a single eye at rest or in motion. We now approach another set of physiological phenomena in which the relation of one eye to the other must be taken into account. It is necessary at the outset to recall a fundamental principle which controls all associated action of the two eyes. In popular language this is called "the desire for single vision." It has been said, more tersely than exactly, that "Nature abhors double vision as she abhors a vacuum," or, transposing a phrase of physics into terms of physiology, we may say that the associated motion of two eyes requires first of all that the image of an object looked at shall fall on parts of the two retinas which correspond to each other.

The main facts relating to corresponding or identical points were first elaborated by Johannes Mueller and were known for many years in ophthalmic literature as Mueller's rule. This, briefly stated, is that if each retina were divided into quadrants by a horizontal and a vertical meridian, each of which passed through the fovea, and if we were to imagine each retina to represent a terrestrial globe, and the fovea as a point of the equator, then identical points on those retinas might be described as having the same latitude and longitude. This is a simple illustration of an important principle which must underlie our study of the eyes together, whether at rest or in motion (B 484-485).

Mueller's rule is sufficiently exact to give a general idea of what is meant by corresponding points of the retina,

although that rule is not absolutely true. Our first object is to learn the position which each eye assumes when it is in a state of so-called "rest," or in its "static condition." This question, which we now approach from the physiological standpoint, is of so much importance clinically that it can be separated with advantage into three divisions. The first, includes this review of facts which relate to the subject in general without reference to any special pair of axes. In the second division we will consider the tests by which we can determine the position of the visual axes when the eyes are at rest; and in the third, those by which we determine the position of the vertical and of the horizontal axes.

§ 2. **On the Measurement of the Interocular Base Line, or the Distance between the Centers of the Eyes.** —We shall have occasion to use this distance in connection with the measurement of relative accommodation and for other purposes. Every ophthalmologist, for example, appreciates the necessity of estimating this distance, at least roughly, in order to prescribe properly fitting glasses, particularly when they are quite strong. The base line may be determined either subjectively or objectively. The former method was adopted by Smee (B 481), who constructed a double-barrel arrangement, the distance between the barrels being adjustable and their centers corresponding with the visual axes.

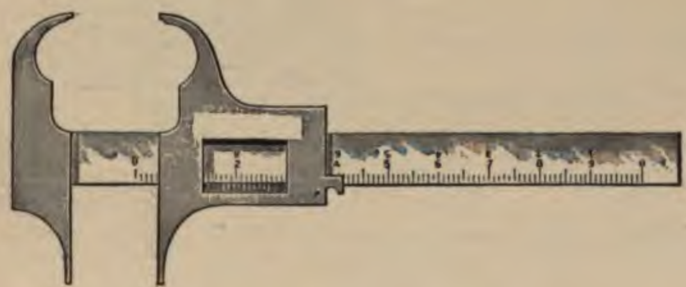


FIG. 150.—Gauge for estimating roughly the distance between the centers of the pupils.

All subjective methods, however, are specially liable to error and therefore have never come into very general use. Objective methods for this purpose are numerous, and several optical firms manufacture a millimeter gauge, sometimes with a vernier (Fig. 150), there being two projecting points to measure the distance between the centers of the pupils. For the work of an optician such a gauge is very convenient. The difficulty with all of these is that the observer does not know whether his own eye is exactly opposite the eye observed, and any parallax is therefore not taken into account. In order to obviate this difficulty, I constructed several years ago a simple arrangement (B 482)

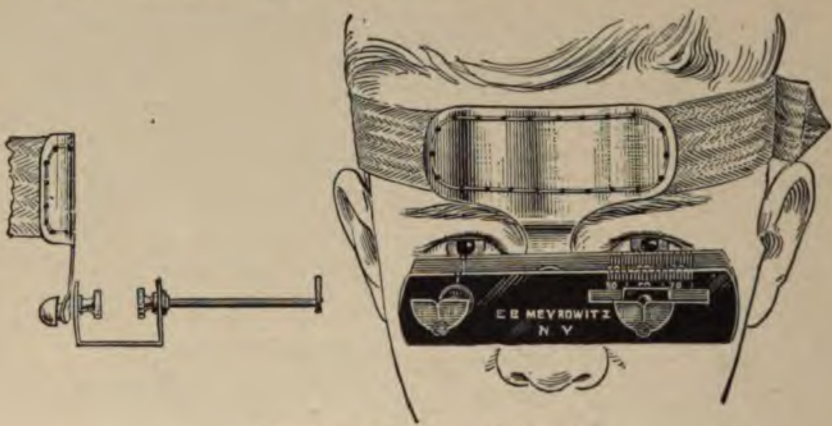


FIG. 151.—Visuometer of the author.

shown in front view, and in section, in Fig. 151. It consists of two millimeter scales, parallel to each other, held firmly just below the level of the eyes by means of a head-band. In order to reduce still farther any error from parallax there are two "sights" which project about fifty millimeters in front of the anterior scale. The illustrations show the construction at a glance. When using the instrument, the observer slides the double scale along the horizontal slot until the zero point with the corresponding stationary projecting "sight" is opposite the center of the pupil of the right eye of the person under examination. The left projecting sight, which moves in a horizontal slot of its own in the anterior

plate, is then slid along its bar until that sight is opposite the center of the pupil of the left observed eye. The exact adjustment of these two sights often requires a little care, but when accomplished, it remains only to read off on the scale the distance between them, and this is the base line. For ordinary purposes it is unnecessary to bind the visuometer on the head. Certainly, for prescribing glasses correctly, all the surgeon needs to do is to hold the visuometer with his left hand against the forehead of the patient, adjust the sights with the right hand, and in a moment read off the distance between the centers. The arrangement which Hess (B 483) has devised to measure the base line (Fig. 152) consists essentially of a scale placed before the observed eyes and two small sights, over which the person under examination looks at a distant object. The observer reads off the length of the base line on the scale. While this is simple in theory it is not always easy to manipulate exactly, but is nevertheless one of the best and most convenient arrangements for the purpose.

FIG. 152.—Visuometer of Hess.

When special exactness is desired for laboratory purposes, I have found (B 482) that the base line can be measured conveniently as follows. The person under examination fixes the head in the head-rest, and to its forehead-piece a millimeter measure is attached horizontally. This millimeter measure and the eyes are then viewed through a small telescope which has a micrometer eyepiece. By moving the telescope back and forward, a point is found at which a certain number of millimeters (for example, three) of the measure which is attached to the head-piece just coincides with a certain

number of divisions (for example, one) of the micrometer scale.

A candle or small lamp is placed a meter or more in front of the subject, and at such an angle as to illumine the eyes under examination and also the micrometer scale of the telescope. The patient then fixes some distant object straight in front. As the observer looks through the telescope at the eyes, he sees on each cornea a minute point of light reflected from the candle. The distance between these two points is then counted off on the micrometer scale in the eye piece and the corresponding distance in millimeters is

FIG. 153.—Telescope visuometer of the author.

known. The arrangement is shown by Fig. 153. As the telescope stands in the dark room, its place on the table being marked so that it is always at the right distance from the head-rest, one can measure the base line in this way very quickly and easily.

The importance of some such measurement will appear later. It must suffice here to repeat that a knowledge of the length of the base line is essential in the accurate measurement of relative accommodation, and a convenience in

determining the distance between the centers of glasses, especially when they are unusually strong.

§ 3. **Forms and Nature of Heterophoria.**—The earlier writers on this subject were accustomed to say that the eyes are "at rest" or are "in a static condition" when they are in the "primary position." This "primary position," as we know, is when the visual axes lying in the horizontal plane are parallel to each other and perpendicular to the line joining the centers of the two eyes. It is impossible here to discuss any of the numerous theories relating to this subject. Suffice it to say that the studies of Edmund Hansen Grut (B 507) have been an important factor in shaping ophthalmological opinions concerning the position of rest and the causes of what we call strabismus. His view that the eyes naturally tend to diverge has been adopted by many English writers, and followed closely by Landolt and Galezowski, but in American and German literature we find comparatively little about it. Indeed, in this country we had, until lately, held to the earlier idea that the primary position is also the position of rest. Fortunately, during recent years we have improved our methods of examination, and therefore approach the question better equipped than before.

But if we attempt to make use of these later methods of examination or tests of the muscle imbalance which are so constantly employed in practice, we must first decide whether the tests themselves are of any value, and if so, which are the most reliable; also what rôle the eyes themselves play in any such examinations. In most text-books these "tests" are described in the chapter on heterophoria—that is, in connection with pathological conditions. But before we can judge intelligently of the importance of any such measurements of diseased eyes, we should try these same tests upon normal eyes. *A physiological standard* is what we need. It is also what we lack. We must agree now upon that standard, even though it necessitates a considerable digression. In any such examination it is assumed:

A. That the subject is of average intelligence;

B. That he has binocular vision; and

C. That the head can be placed in exactly the same position whenever desired.

The problem before us is to ascertain the position of the visual, and also of the vertical or the horizontal axes in the position which we call "rest." For the present we will consider that the word rest means simply a relaxation, to as great an extent as possible, of the extraocular muscles, although we shall find that this is only an *apparent* rest. However that may be, the fact is that eyes which are perfectly normal otherwise, and which never gave their owners any inconvenience, when placed in the position of *apparent* or of *actual* rest often tend to deviate from the primary position into positions more or less abnormal. It is therefore proper at this point to recall at least a few of the terms which describe these positions (B 725).

Orthophoria, is usually described as the "tendency of the visual axes in parallelism."

Heterophoria, the tendency of the eyes to turn in any other direction.

Esophoria,[1] the tendency of one or both eyes to turn inward.

Exophoria, the tendency of one or both eyes to turn outward.

Hyperphoria, the tendency of one eye only to turn upward.

Anophoria, the tendency of both eyes to turn upward.

Hypophoria, the tendency of one eye only to turn downward.

Katophoria, the tendency of both eyes to turn downward.

Cyclophoria, the tendency of one or both vertical axes to revolve in or out about the antero-posterior axis.

Besides glancing thus at the different forms of heterophoria, it is essential to recall also their real nature. We should keep in mind the fact that they are all essentially *passive* conditions. In order to know whether or not heterophoria exists, it is necessary, in all of our tests, first to dissociate the retinal image in one eye from that in the fellow eye, and having thus removed all tendencies to single vision, each globe swings, or tends to swing, into the position most natural to it. In other words, every form of heterophoria requires the constant effort of one or more groups of the muscles, that

[1] Ĕsophoria, not eesophoria, as it is sometimes pronounced.

is, a corresponding *duction*, to overcome it, as long as single vision is maintained. If that effort is excessive or insufficient, or if not in accord with certain fundamental principles which we shall see control muscle balance, then it gives rise to a large group of annoying symptoms. Their character will be studied later from the pathological standpoint.

In any attempt to ascertain the position of the visual axes by means of appliances or tests, we have to do with two factors. One of these is the instrument used, with its concomitants, and the other is the eye of the individual. It will be found convenient to consider each of these factors in order.

§ 4. **Precautions Necessary with All Tests—The Environment.**—In considering the instruments now at our command for this purpose, we have to do with the appliance itself, and also with the environment—that is, the room, the test light, etc. It may seem elementary to refer to such simple matters, but a variation in these details certainly causes a variation in the results, and as the chief object here is to eliminate confusion, the methods employed must be as nearly uniform as possible. As these concomitants are the same for all the tests, it is easier to consider them first.

(A) **The Room.** Results perceptibly more constant can be obtained if the tests are made in a darkened room six meters or more in length. Evidently such rooms are not obtainable by the average practitioner in a crowded city, and are to be found only as parts of an ophthalmological laboratory. But this means, practically, that when replies in the consulting room are contradictory, particularly those of an apparently stupid subject, the answers will often be less confusing if the same tests are made in the same room at night.

Thus we find that the Maddox rod, an admirable test in many respects, is practically useless, even for an intelligent patient, if the room is so bright as not to allow the streak to be plainly visible, or if there are adjacent to the test light, bright points from which that light itself is also reflected, and thus, by giving several streaks instead of one, confuse the patient into contradictory replies. It is desirable at least to have a board about a meter square or a space of that

size behind the test light covered with black cloth or paper, in order to avoid points of reflection.

(B) **The Test Light.** As most of these tests are made with a light placed at a distance of six meters or more, we should understand what kind of a light is referred to. We are accustomed to think of a candle flame as the most convenient, especially as that is the light usually figured. The fact is, however, that this is inconvenient and inaccurate. Not only does the flame bend from side to side with each draft of wind, but it varies in height. This is especially annoying when exact tests are desired with regard to the tendency of the eye to turn up or down. For that reason, if a candle is used, the flame should be enclosed in an opaque cylinder like that which Landolt proposed, having a circular opening on one side. The best form is that in which a gas or an electric light is screened behind a circular opening,—as, for example, in the Thorington chimney (Fig. 154).

FIG. 154.—Thorington's chimney.

(C) **The Head-Rest.**— For routine office work with ordinary patients, it is sufficient to instruct the person to hold the head erect and still, but when the most exact results are desired in physiological studies, or with restless patients, especially children, it is more satisfactory to use the head-rest already described (B 553.)

As we sometimes wish special accuracy when using prisms singly or in the form of the phorometer, the latter instrument has been attached to the head-rest, as in Fig. 155. The arrangement is such as to permit adjustment of the phorometer to the height of the eyes, or to allow it to be swung entirely away from the face, when it interferes at all with changes of glasses or with other manipulations.

Doubtless many an ophthalmologist may insist that such precautions regarding the room, the light, and the adjustment of the head, etc., are entirely unnecessary.

FIG. 155.—Head-rest of the author with phorometer attachment.

It is quite true that very fair clinical work can be accomplished by the cruder method of placing a candle in the distance and holding a prism in the hand before the eye of the person under examination, but as one of the main objects of this study is to obtain results as constant as possible, it becomes an evident necessity to employ exact methods.

Laboratory procedure is sometimes quite different from that of the consulting room, but after practice with the former it is unconsciously followed as part of the clinical routine, to the satisfaction of the practitioner and the advantage of the patient.

DIVISION II.

Tests to Determine the Position of Rest of the Visual Axes.

§ 1. **Classification of the Tests. — First Group.** — We assume that we are able to determine the position of rest of the visual axes by means of tests which depend on the fact that, when the tendency to binocular vision has in any way been abolished, each eye actually does swing, or at least tends to swing, into that position which it can occupy with the least amount of effort. For the present we will grant that assumption, although a little later we shall see that this tendency is subject to various modifications. The tests employed are the witnesses, as it were, in the case before us, and upon their evidence we must decide. Let us, therefore, bring them before us, and note the nature of the evidence furnished by each. After that, we can observe whether any witness contradicts itself at different times, or whether the witnesses contradict each other. Usually students appreciate better the uses of the tests for heterophoria if they are arranged in three groups. Disregarding the chronological order in which they were described, and omitting some of their modifications, we can arrange these tests, according to their action, in three groups. Thus we have:

First, *a group in which the retinal image in each eye remains clear, but one or both of these images is displaced from the macula by means of a prism with the base up or down, before one eye or both.*

Here we have:

A. The single prism, base up or down, as first suggested by Graefe.

B. That modification of the single prism which we know as the phorometers of Stevens, Savage, and others.

(A) The prism or prisms, base up or down.

Graefe applied the principle here involved to a vertical line drawn through a dot, viewed at the near point. But as that

involved the acts of both accommodation and convergence, and as we are now studying both eyes at rest, evidently the test object must be situated six meters distant. For this purpose the test object is the bright circular opening in an opaque chimney already described. With all these methods the test depends on the use of one or two prisms, and this method, even though familiar to most readers, should be described if only for the sake of completeness.

When, for example, a prism is held base down before the right eye, as the observer looks at a distant light, the image of this light falls on the lower part of the retina of that eye.

FIG. 156.— Positions of the retinal images as seen from behind in orthophoria.

If orthophoria is present, the retinal image of the right eye is displaced from F to F′ (Fig. 156), and the light seen through the prism with that eye is straight above the one seen directly with the left eye. But if the right eye tends to turn inward (Fig. 157), then the image of the light falling on the

FIG. 157.—Positions of the retinal images as seen from behind in esophoria.

lower and inner portion of the retina F′ causes the light to appear above and to the right of the real one seen with the left eye. Moreover, the amount or the number of degrees which the right eye turns inward is then shown by the strength of a second prism held with its base outward, in front of the first prism, so as to deflect the image outward

sufficiently to fall directly below the macula of that right eye. In other words, this horizontal prism changes the position of the retinal image of the right eye from F′ to F″. The two images of the light then appear in a vertical line. In a similar manner, if the right eye tends to turn outward, the image of the light falling in the lower and outer portion of the retina seems to be above and to the left of the real light. The amount which the eye turns outward is shown by the strength of a second prism, base inward, which brings the two lights into a vertical line.

It is easy to see that this experiment could be varied in many ways. One of these is to arrange a scale for the speedy and accurate determination of the position of the eyes, such as has been constructed by Herbert (B 533). This scale consists of a black background with several white squares to the right, left, up, and down respectively from a central square, thus forming a cross, each spot being one centimeter square and so arranged that the separation of each square is

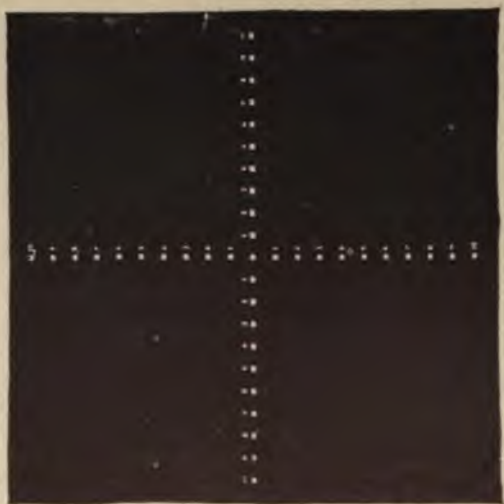


FIG. 158.—Herbert's arrangement of dots for testing and measuring heterophoria.

equivalent to a deflection of one prism diopter. If the squares are to be viewed at a distance of five meters, they

must be drawn five centimeters from center to center. If, however, that distance from the scale to the patient is not convenient, any other may be chosen, the rule being that for every decrease of one meter, the distance between the squares must be decreased one centimeter, and for every increase of one meter the squares must be separated one centimeter. Figure 158 illustrates the arrangements of the dots or small squares. White squares can be cemented on black, or black ones on a white back-

FIG. 159.—Same arrangement in orthophoria with a prism of five degrees base down before right eye.

ground. The scale should be hung up in a good light, opposite a window if possible, the center of the scale being on the same level as the patient's eyes. By placing a 5-degree prism base down in front of one eye, the cross will be deflected upward five squares, and if orthophoria is present there will be two horizontal arms, as shown in Fig. 159. But if esophoria is present, and we place a prism base down before the right eye, then the second cross

is seen above and to the right (Fig. 160), or with exophoria it would be seen above and to the left.

FIG. 160.—Same arrangement in esophoria.

(B) That modification of the single prism which we know as the phorometer of Stevens (B 514) (Fig. 161), depends on the same principle, except that two prisms placed opposite each other are used, one with the base down, for example, before one eye, and another, with the base up, before the other. As these prisms are revolved in opposite directions, the images of a distant dot or point of light change their relative positions, and the degree of the heterophoria, if any is thus revealed, is read off on a scale calculated for that purpose. Instead of placing one prism before each eye, Risley (B 508) obtains the same effects by mounting both prisms together in such a way that they revolve on each other, both before one eye. The principle involved is similar, as we see at a glance, to that of the Stokes lens. This form of the prism is convenient and has decided advantages, but is not quite as exact as the more elaborate arrangement of Stevens. The same may be said also of others of this type.

(C) The double prism of Maddox (Fig. 162) consists of two prisms, each of about four to six degrees, joined at their

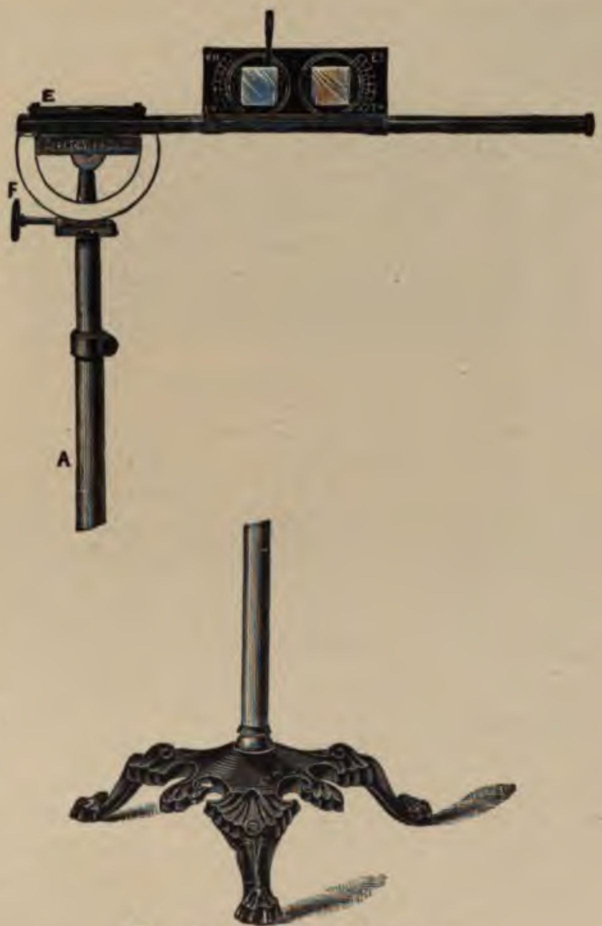


FIG. 161.—Phorometer of Stevens.

FIG. 162.—Double prism of Maddox.

bases. When these are held before the right eye, for example, with the line of their bases horizontal, the upper prism

FIG. 163.—Action of the double prism.

deflects the image of the distant test light upon the lower part of the retina, and the lower one deflects another image of the light upon the upper part of the same retina (Fig. 163.)

In this way the observer sees three lights. If orthophoria is present, they are in the same vertical line, and the central one (seen with the uncovered eye) is half way between the other two. If the prism is held thus before the right eye, in esophoria the middle light of course appears to the left of the other two, in exophoria to the right. In right hyperphoria, it appears nearer the lower light. In right hypophoria, nearer the upper light, etc.

§ 2. **In the Second Group** *the retinal image falls on the macula in each eye—in one with the usual clearness, but in the other with the image so distorted or blurred or changed in color as to abolish all effort at fusion.*

FIG. 164.—Glass rod of Maddox, simple form.

FIG. 165.—Compound glass rod of Maddox.

As the best types of this group we have:

(A.) The glass rod of Maddox, simple or compound, in its various forms.

(B.) The stenopaic lens.

(C.) The cobalt glass.

FIG. 166.

FIG. 167.

FIG. 168.

Tests of the static position when a glass rod is held horizontally before the right eye and the person under examination looks at the round opening in the chimney. (166) Appearance seen in orthophoria; (167) in esophoria; (168) in exophoria.

If the visual axes of the two eyes are in the same horizontal plane, the horizontal streak of light will pass through the center of the test light (Fig. 169). If the axis of the right eye tends to turn upward, the streak will appear below the light (Fig. 170), or if the axis tends to turn downward, the streak will appear above the light (Fig. 171).

B. The stenopaic lens (B 515). When a lens of small diameter (Fig. 172) and of 12 or 13 diopters focal length is held before the right eye, for example, and the observer

FIG. 172.— The stenopaic lens (Stevens).

looks at a distant light, it produces on the retina a blurred image of the distant candle or point of light. If the visual axes are parallel, the light appears to be in the center of the blurred spot (Fig. 173 *C*), but if the right eye turns outward, the image of the blurred disc, being then projected inward, the light appears to be nearer its right edge, or if it turns out and downward, the blurred image being projected up and to

FIG. 173. —Action of the stenopaic lens when the axes are (*C*) parallel (*D*) not parallel.

the left, the light appears to be near its lower and right-hand edge (Fig. 173 *D*).

FIG. 174—Cobalt glass (Ridgeway).

C. The cobalt glass. If a piece of colored glass (Fig. 174) preferably of a dark cobalt blue, of such thickness as to allow only a little light to pass through it, is held before one eye while the observer looks at a distant candle or spot of light, he sees only an indistinct image of the light. In other words, this acts like the stenopaic lens, and tests made with the blurred spot of colored light are similar in every way to tests made with such a lens.

§ 3. **A Third Group** *of tests includes those in which, one eye being covered with the hand or by a screen, and thus excluded entirely from the visual act, it swings into the position most natural to it.* When deviation occurs under such circumstances, we have, *subjectively*, the so-called *parallax test*. Then, by quickly uncovering the excluded eye, there is diplopia for an instant, and an apparent movement of the test object as single vision is re-established. Also we have,

objectively, displacement or a momentary malposition of the eye of the subject, which the surgeon sees just at the instant when the hand or card is withdrawn.

With some clinicians this is a favorite test (B 553–565). It is true that the more intelligent patients will recognize the displacement which the object presents at the instant when the card which covers one eye is removed. But although this test is very simple in theory it often requires skill in both patient and surgeon. Many of the former, especially those who are uneducated or naturally dull, are utterly incapable of estimating the distance which seems to exist between the real light and the one which appears to be displaced at the instant when one eye is uncovered. This is especially true when the vision of both eyes is not quite the same. This cover test, therefore, apparently cannot be considered one upon which to rely, either objectively or subjectively.

The diploscope of Remy, however, deserves mention. The principle upon which it is based is similar to the cover test, and can be understood better by a simple experiment in parallax. If the index finger be held vertically and at arm's length in front of the face, while the observer looks with both eyes at a series of four letters,—for example, K O B A— arranged in a horizontal line across the room, it is possible to place these letters at such a distance from each other and from the observer that, with his visual axes parallel, he can, by closing his left eye, see only K B, and by closing the right he can see only O A. If, however, by placing suitable prisms before the eyes, a tendency for the visual axis to turn inward or outward is created, or if esophoria or exophoria exist, then with the letters and with the finger remaining in the same position he may read K B A or K O A, or other combinations depending upon the position of the visual axes.

Now the essential part of the diploscope also consists of a screen similar to the finger in the median line. In the earlier form of the instrument it was a vertical strip of brass, a little wider than a finger and about as long, which could be placed vertically or turned horizontally as desired. Later a disc of brass about eight centimeters in diameter was perforated

with two circular openings (Fig. 175) each about twenty millimeters in diameter, the distance between the adjacent edges of these openings being about fifty-five millimeters, or

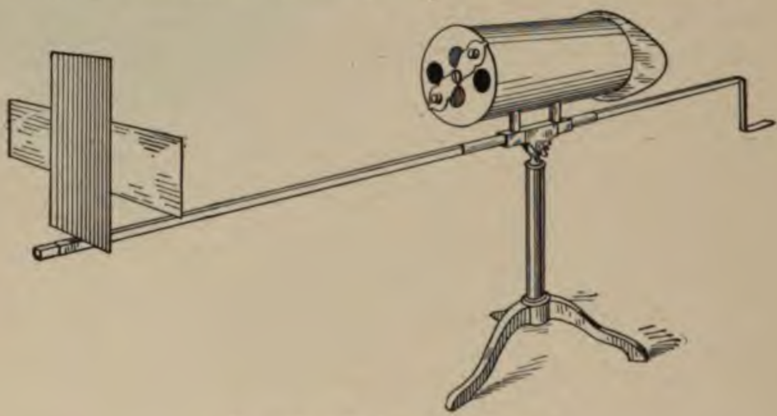


FIG. 175.—Diploscope of Remy.

a little less than the distance between the centers of the eyes of the average individual. Therefore the screen of brass between these openings serves the same purpose as the intercepting finger in the simple experiment just referred to. This circular disc is also perforated in its vertical diameter with two other circular openings, of about the same size and same distance from each other as are the horizontal openings before mentioned. The vertical openings are for testing vertical deviations of the eyes. A strip of thin brass, which is a little broader than the diameter of these circular openings, is attached at its center to the center of the disc. By turning this strip it can be made to cover the two vertical or the two horizontal openings as desired.

While this simple disc is the essential part of the diploscope, for convenience and accuracy, something depends upon its being properly mounted, so as to place it and keep it at the proper distance from the eye. In order to shut out extraneous rays, this disc is placed at the farther end of a tube of brass some twenty or thirty centimeters long, the proximate end being left open. A square brass rod about a meter in length is attached near its center to the lower

side of this cylinder. At the distal end of the rod there is a rack which holds the test letters, and at the proximate end there is a short step in the bar upon which the chin of the person can rest when the tests are made, thus keeping the eyes always at the same distance approximately from the screen and of course from the letters. The entire instrument is mounted on an adjustable foot-piece to give it stability, and the upright arranged so that it can be adapted to the position and height of the individual.

This brief glance at the structure of the diploscope is sufficient for our purpose. Its use is indicated by the simple experiment in parallax already cited. The fact that a person can see with the instrument the four letters K O B A or three of them, or two, indicates, as before mentioned, the position of the eyes. The truth is that, after having tested this method quite thoroughly, it has seemed to me at least, one of the least convenient or exact with which to determine the static position of the eyes, although some practitioners, rely upon it almost entirely. It is, however, exceedingly useful in showing the presence of binocular vision, and especially in detecting cases of malingering.

§ 4. **Which of these Methods is the Best for Determining the Latent Position of the Visual Axis?** — In view of the number of instruments and methods and modifications of both which are constantly proposed, we naturally ask which of all is the best. The confusion of opinions among clinicians on this point shows how essential it is to secure some approach to uniformity. In order to decide this, we must agree upon certain criteria by which the excellence of one method or another can be judged.

First, the instruments must be so constructed that they can be arranged at all times in exactly the same position, and the readings made with the same degree of accuracy. If we examine the instruments in turn, we see that they do not comply equally with that demand. When the single prism is square and is held in a square frame, its position can always be promptly and quite accurately adjusted. Stevens' phorometer in some form is probably the best instrument we have considered from this point of view. With the spirit-level,

the base of the prism can easily be placed horizontally, and if the index is properly constructed, the readings are easy and always accurate.

Second, the retinal image which the test object forms must be of such a kind as to produce no confusion in the results, or at least the minimum amount possible.

This requisite has to do with the perceptive power of the retina, as well as with the test itself. The influence of the muscles, retina, and brain upon the apparent static condition of the eye will be considered later. But just at present let us confine ourselves to the question of the degree in which the different tests comply with this second demand. Here again the tests of the first group are quite satisfactory, as are those of the second group also.

When the streak of the glass rod is clearly visible, the exact vertical or horizontal position of the streak is readily recognized. As for the stenopaic lens or the cobalt glass, the nature of these instruments is such that they readily conform to the first requirement, though they do not to the second.

The tests of the third class evidently do not fulfil the first requirement. Of course it is as easy to exclude one eye at one time, as at another, but it is impossible to measure accurately either the parallax, which is observed by the patient or the displacement, which is observed by the surgeon.

Without going into further details here, it may be stated in general that tests of the first group tend to give more constant results than those of the second group, and these, more constant results than those of the third group.

From the foregoing, therefore, it is evident that the tests here described are by no means all of equal clinical value, and an arrangement according to their order of excellence would be apparently about as follows:

1st. Stevens' phorometer.
2d. Graefe's prism, when accurately placed before the eye.
3d. The compound colored Maddox rod.
4th. The stenopaic lens, the double prism, and the colored glass.
5th. The cover test either subjectively or objectively.

Such an arrangement is of very decided practical import-

ance. It is true that the relative value of some of these tests has been discussed by Stevens (B 514), Hubbell (B 548), and others, but much greater exactness is necessary before we can lessen materially the existing confusion concerning muscular statics. We must have a scale of values for these tests, such as is given here, or one more accurate, as determined by future experiments. The text-books should not give to each test the same apparent value, as is usually done, but should make clear the usefulness of some, and the uselessness of others. Finally, when a writer makes any statement relating to muscular statics he should also make it a rule to specify, with other details, which test or tests have been employed. Until this is done, our present confusion must continue.

§ 5. **What is the Influence of the Eyes in Determining the Static Position of the Visual Axes ?**—The foregoing tests, alone or together, constitute one factor in determining the position which the visual axes assume or tend to assume. The second factor is the influence exerted by certain parts or functions of the eyes. These are:

(A) The ciliary muscles with the corresponding function of accommodation. It is often taken for granted that a pair of eyes is entirely "at rest" when they are in the primary position. That, we know, is not necessarily the case, for no one can say what is the condition of the ciliary muscle without also measuring the refraction. In cases of hypermetropia, some tension of that muscle of course is necessary if the person sees distant objects clearly.

Again, a familiar experience indicates that the eyes are not necessarily "at rest" when they do assume the primary position. When we use almost any one of the test instruments of the first or second class—for example, the glass rod,—we notice that as the subject looks at the distant light the vertical streak *does not remain stationary*. Frequently this streak apparently swings several times from side to side. But as the rod is stationary, and as the head is also stationary—or should be—evidently that motion of the streak must be due to the action of the recti muscles. But as the recti muscles in turn are intimately associated with, and partly dependent

upon the ciliary muscles, the latter in reality thus influence very decidedly the static position of the visual axes.

The influence of the ciliary muscle in determining the static position of the visual axes is also shown by the fact that without atropin the foregoing tests, when made on certain individuals, give more or less conflicting results, whereas after a sufficient use of atropin these results tend to greater uniformity.

(B) The recti muscles influence the static condition of the visual axes. In certain cases, after a cycloplegic has been used and a perfect correction of the ametropia made, if the rod be placed before one eye horizontally, the patient will still assert that the vertical streak moves from side to side before it assumes a position of rest. Evidently this must be due to an action of the recti muscles alone. There are other facts which point in the same direction, but this simple experiment is apparently conclusive.

(C) The condition of the retina influences the static position of the visual axes, through the ability or inability of the individual to perceive a displaced or blurred image. Certain persons find difficulty in recognizing such an image, even though it is clearly formed; and occasionally one is met with who cannot distinguish it at all, even though he be intelligent and the retina normal, as far as can be ascertained.

§ 6. The so-called "Position of Rest" is either APPARENT or ACTUAL. As the action of the ciliary muscles, either alone or in conjunction with the recti, constitutes a large factor in the tendency to error in these tests, it seems desirable, from the standpoint of the physiologist and especially from that of the clinician, to separate the condition which we call "rest" into two forms. The first, or *apparent rest*, is simply a relaxation, more or less complete, of the extraocular muscles. The second, or *actual rest*, is relaxation not only of the extraocular, but also of the intraocular muscles. It is true the difference is usually not great, and in most cases can be disregarded, but when muscle imbalance persists for a long time and in any annoying degree this difference should certainly be taken into account as a part of the diagnosis and therefore as a factor in the treatment. Until that difference

is recognized, the clinician does not always know what he is measuring, no matter how exact may be the instruments or his method of using them. Also, when uncertain results are recorded they are confusing to himself and to others. The practical importance of this point is too evident to require any elaboration.

§ 7. **What then is the Usual Position of the Visual Axes when Normal Eyes are in a State of Apparent Rest ?**

The first reliable tests were made by Bannister upon the eyes of one hundred soldiers at Fort Leavenworth in 1897 (B 579). At present we will consider only what *appeared* to be the static condition. The results which he obtained were striking and instructive, in showing that orthophoria was by no means necessary to comfortable vision, as had formerly been supposed. Partly to verify these figures and to exclude sources of error, tests were made of the static condition of the visual axes among other soldiers stationed at Fort Porter, who were being examined partly with reference to this and also as to other phases of their muscular condition. The results obtained by Bannister, those which I obtained, and the result of a third group (of Harvard students) who were measured by Dr. Chas. H. Williams and myself, are found in the following table.

Examiner	No.	Occupation	Orthophoria	%	Esophoria	%	Exophoria	%	Vertical Deviations	%
Bannister	100	Soldiers	60	60	29	29	7	7	7	7
Howe	56	Soldiers	22	39	18	32	9	16	7	12
Williams and Howe	31	Students	12	38	10	32	4	12	5	16
	187		94	50	57	30	20	10	19	10

Quite recently this question was investigated by Bielschowsky and Ludwig (B 580), their object being to ascertain not simply the percentage of heterophoria as compared with orthophoria, but also the percentage of heterophoria in

healthy individuals as compared with that which exists among neurotics and also among those who have what is commonly called muscular asthenopia. These findings will be considered in detail when studying the pathology of the muscles. It is sufficient in this connection to state that these two observers also found heterophoria much more common in normal eyes than is orthophoria, and it may be added that, according to them, heterophoria exists quite as frequently in the normal as it does in the abnormal conditions just mentioned.

It will be observed that the percentages found by different examiners differ somewhat from each other. I have taken pains, however, to inquire by letter of both Bannister and Bielschowsky as to the probable causes of this, and it seems altogether probable that such differences are due in part to the different methods of making the examinations.

From the data thus far obtained we must conclude concerning the *apparent* position of rest.

1st. Orthophoria is not present in the majority of normal eyes.

2d. Esophoria is almost as common as orthophoria, exophoria is less common, and vertical variations probably the least common of all.

§ 8. **The Conclusions Regarding the Static Position of the Visual Axes are:**

1st. The methods ordinarily used for determining the static position of the visual axes are not altogether satisfactory. This is because:

a. Different tests in constant use are of different value; and

b. Certain parts or functions of the eyes themselves influence the position of the axes.

2d. In order to obviate these difficulties and to ascertain as nearly as possible the actual static position of the visual axes, it is desirable to have:

(A.) A suitable room in which to make the examinations.

(B.) A proper test light.

(C.) To employ always the same test in exactly the same way.

(D.) If extreme exactness is necessary, it is desirable to

have the eyes of the subject under the full effect of a cycloplegic.

(E.) To correct any existing ametropia.

3d. Unless these precautions are taken, we do not ascertain the *actual* but only the *apparent* static position of the visual axes.

4th. As the apparent static position of the visual axes is quite variable, being dependent on different factors, it is evident that any conclusions as to diagnosis or treatment based on that finding alone are also inexact.

5th. It would tend to accuracy if an Ophthalmological Congress would agree upon uniform methods of testing and of expressing the results of such tests of the static position of the visual axes. Until more scientific and uniform methods are adopted, we must continue to have confusion in diagnosis and treatment.

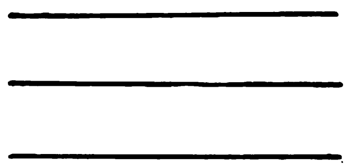
DIVISION III.

§ 1. Tests to Determine the Position of the Vertical Axes. Does the Eye Rotate on its Antero-Posterior Axis to Reach a Position of Rest?—In our study of the eyes at rest, we have considered thus far only those tendencies (forms of heterophoria) in which the visual axes turn in, out, up, down, or obliquely. It is evident, however, that there may also exist a tendency for the *vertical axes* to revolve about the antero-posterior diameter in order to assume a position of most complete rest. The position of the vertical axes when the visual axes are parallel, and also when they converge, was long ago investigated by Volkmann (B 581), Helmholtz (B 584), Hering (B 586), and several others. It might suffice in one way for our present purpose to make the simple statement that when the eyes are in the primary position the vertical axes tend to diverge upward at an angle with each other of about three degrees.

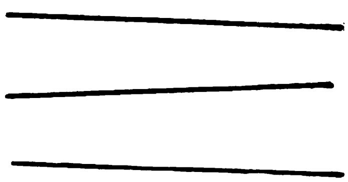
As this angle is so small as to be hardly perceptible by most measurements, it may seem unworthy of much attention—indeed, in itself it is of no clinical importance. But the fact that the vertical axes do thus revolve about the antero-posterior axes brings us to one phase of that important function which we call *true torsion*. It will save much confusion therefore and considerable repetition, if at this point we glance at the methods by which it is possible to determine the position of the vertical axes when the visual axes are in the primary position. Most of the earlier students of this subject depended in part upon the fusion of two similar retinal images which were vertical or nearly vertical. The tendency of the muscles to fuse such images will be considered in detail later. For our present purpose we must consider certain tests which *dissociate* the retinal images entirely or at least in part, thus allowing each globe to rotate into the position most natural to it. Most of the tests of this

kind for determining the position of the vertical axes have come into use comparatively recently. Therefore a disregard of the chronological order of the description of the tests for determining the position of the vertical axes enables us to group them, as we have already grouped different tests for determining the position of the visual axes when the eyes

A



B



C

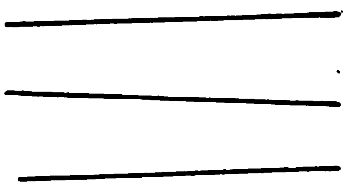


FIG. 176 — Appearance presented by forms of heterophoria when a double prism, bases horizontal, is held before the right eye and the observer views a distant horizontal line. (A) Orthophoria; (B) tipping of the vertical axes inward; (C) tipping of the vertical axes outward.

are in a state of apparent or actual rest. Indeed the groups are in a certain way similar to each other. Thus we have:

§ 2. *First a group in which the retinal image in each eye remains clear but one of these images is displaced from the*

macula by means of a double prism. This has been described (Chap. III – Div. II – Sec. I), and we have seen how its use with a distant test light enables us to detect latent deviations of the visual axes. The same prism enables us to detect also latent deviations of the vertical axes. For this purpose we use a horizontal line as a test object. For example, if such a prism be held before the right eye while the individual looks at a horizontal line, if orthophoria is present, then when the left eye is also open the observer sees three lines which are parallel to each other (Fig. 176 A), the one viewed with the left eye being half way between the two produced by the prism. But if there is a tendency for the left eye, for example, to revolve about its antero–posterior axis, this third line, which belongs to the left eye, is no longer horizontal, but it is tipped obliquely in one direction or the other. (Fig. 176 B and C). This subject has been elaborated by Savage (B 462) in a manner quite familiar to American readers.

Various slight modifications of this test have been suggested, but they depend upon the same principle or are so nearly identical with it that they need not be dwelt upon here.

§ 3. **The Second Group of Tests** *includes those in which the image of the test object falls unchanged on the macula and a part of the retina of one eye, and the image of another test object falls unchanged upon the macula and another part of the retina of the other eye.*—These test objects are usually in principle at least, some form of the Volkmann discs. Their forms will be referred to more in detail a little later. At this point it is sufficient to say that he was one of the earlier students of this question and suggested measuring the position of the vertical axes by means of vertical radii (not with diameters) drawn on two circular pieces of cardboard (B. 581). At present we will confine our attention to these two discs a single radius on one being directed upward, and on the other, downward (Fig. 177). These discs are of such a size that the distance between their centers can be made to correspond to the distance between the centers of the eyes under examination. By turning one or both of

the discs a few degrees in or out, it is possible to determine at what point the two radii seem to form a single vertical line. Since the time of Volkmann, the same experiments have been repeated by many others and several appliances based on this principle have resulted.

FIG. 177.—Volkmann's discs, simple form.

(A) **Stevens' Clinoscope.**—Stevens (B 598) placed one of these discs at each end of a tube and called the arrangement a

FIG. 178.—Adaptation of Volkmann's discs to the clinoscope of Stevens.

clinoscope (Fig. 178). The most recent model of this consists essentially of two brass tubes each about twenty cen-

timeters long and two or more centimeters in diameter. At the distal end of each tube there is a Volkmann's disc (tipped sometimes for convenience) and at the proximal end a small opening, the distance between the tubes being adjustable to correspond to the distances between the centers of the pupils. The illustration shows at a glance the excellent mechanical arrangement for levelling the instrument, for measuring the amount which each disc is revolved around the axis of the tube, and the amount which the tubes are elevated, depressed, etc. Stevens' clinoscope is not adapted, however, for measuring the tipping outward of the vertical axes in the act of convergence for the reason that the tubes cannot be made to converge sufficiently.

(B) **Another Form of the Clinoscope.**—We will see later that the principal use of an instrument of this kind in clinical work is not for determining the position of the vertical axes when the eyes are at rest—the point which we have now under consideration,—but it is rather to determine the position which those axes assume when the visual axes converge. It therefore seemed desirable to arrange the discs so that we could measure with them the position of the vertical axes when the eyes are in the primary position *and also* when the visual axes converge. This was accomplished by taking away the tubes entirely, placing the discs directly before the eyes, as Volkmann did, and then providing a simple but accurate means by which the discs could be set at any desired distance from each other or from the observer. The form which seemed to serve this purpose best is, in substance, as follows (Fig. 179).

First. A head-rest (F F′). This is a modification of the Helmholtz bit which has been already described

Second. A median bar (H H′) which rests at each end upon an upright and whose height can be adjusted as desired.

Third. A transverse bar (B B′) which measures on section about five millimeters square and which, being attached to the carrier T slides along the median bar H H′. The transverse bar has, on each side, a small carrier, supporting a metal frame. In the figure this is obscured by the Volkmann discs. In front of the lower half of this metal frame

there is a grooved arc, and in this a disc (V and V′) rests. The upper part of the metal frame supports a graduated arc (D D′). An index attached to each disc indicates on this graduated arc the exact position of the radii.

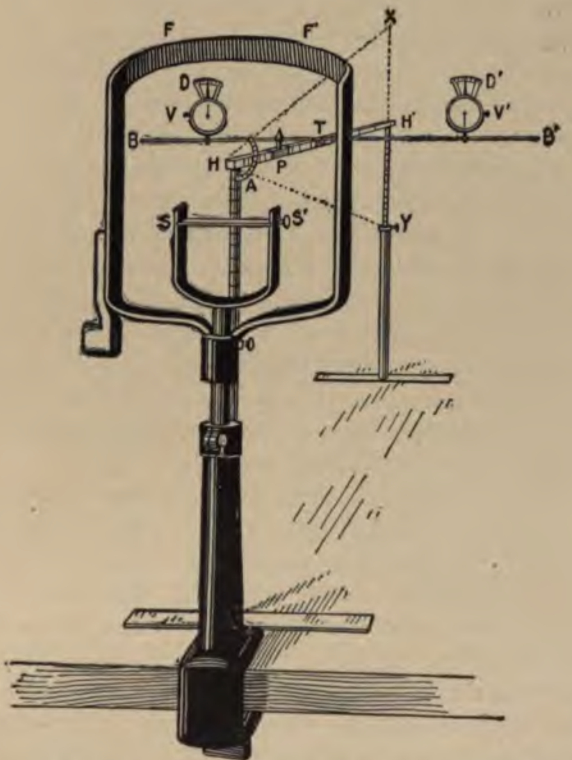


FIG. 179.—Adaptation of Volkmann's discs to the converging clinoscope of the author.

Fourth. A second carrier (P) on the median bar bears a small projecting point whose height can be raised or lowered as desired by a screw thread and its upper portion is deeply indented by a narrow notch. The object of this projecting point is to hold a card or other screen in the median line, when the Volkmann discs are viewed with the eyes in the primary position. Or, if the instrument is used to measure the position of the vertical axes when the visual axes con-

verge, then this projecting point serves as a point of fixation. There are other details which assist in these measurements of convergence, but they need not detain us in this connection. Let us suppose for our present purpose that we wish to measure the amount of tipping of the vertical axes which occurs when the visual axes are in the primary position. To do that, the carrier T is pushed toward the distal end of the median bar at H′; the discs (V V′) are then brought near to the bar so that the distance between their centers is the same as the distance between the centers of the eyes. Some persons, at least with a little practice, can then dissociate the retinal images in such a way that the right eye sees only the disc (V′) and the left one the disc (V). Ordinarily, however, it is necessary to fix a card as a screen in the median plane in such a way that each eye is prevented from seeing the disc which is opposite the other eye. In that way the images of the discs can be blended and the instrument thus serves the same purpose as the Stevens clinoscope when that is adjusted to measure the position of the vertical axes with the eyes in the primary position.

§ 4. **What is the Usual Position of the Vertical Axes when the Visual Axes are in the Primary Position?**—The foregoing descriptions of the different methods of measurement have been given not only that we may know how these measurements are made, but also how various degrees of cyclophoria can be recognized. The question still remains, however, what is the normal position of each vertical axis? It may therefore be repeated that the physiological vertical axes are *not* absolutely vertical, but when the eyes are in the primary position these axes are inclined downward toward each other, at an angle of from about three to four degrees — on the average, about three and one-third degrees. It is unnecessary to go into detail concerning slightly different results obtained by different observers and the probable causes of these differences. Suffice it to say that measurements made more recently agree in general with those by the first observers already mentioned. This inclination of the vertical axes from the median plane is so slight that it need not usually be taken into consideration.

Indeed, while understanding that the verticals are thus inclined to each other, it is customary to speak of them as if they were actually vertical. This will therefore be done in what follows except when special exactness is desired.

§ 5. **Which Test for Cyclophoria is the Best?**— Having thus glanced at a few of the different tests for cyclophoria, the question arises, which is the best either for laboratory measurement or for clinical work? It is unnecessary to review the various criteria by which any such tests are to be judged. Suffice it to say that as the double prism is the simplest and the one most readily understood, it commends itself most for clinical work. It is also the one upon which practitioners usually depend if they take the trouble to make any tests of this kind. It is, however, by no means exact. It simply indicates, in a general way, what the condition is, and although an approximation to the degree can be obtained by placing a proper prism before the other eye, that method is also inexact.

For all reliable measurements and physiological studies, some form of the clinoscope is essential. Office patients, after a little practice with the instrument, usually give intelligent replies as to the position of the lines, and such measurements are of course infinitely more satisfactory than can be obtained with the double prism. But these tests with ignorant or stupid patients result only in confusion and vexation of spirit.

§ 6. **Exactly what is Cyclophoria?**—Since normal eyes in a state of rest frequently tend to assume some other than the primary position, and since these variations from the normal type occur also in pathological conditions, it was necessary to recall the terms describing these conditions. In other words, it was necessary to define the various forms of heterophoria. Cyclophoria was then defined as a tendency of the vertical axes to turn in or outward from the vertical meridian. That definition is usually sufficiently exact, but we have just seen that under normal conditions what we call the vertical axes are not in reality quite vertical, but that the upper end of each axis tips outward at an angle of from one and a half to two degrees from the median plane. In a strict

sense, therefore, this slight deviation must be taken into account. If in using the clinoscope we find it necessary to tip the upper radius out four degrees before the two radii appear to form a single vertical line, we cannot say strictly that there is a tendency for each axis to turn out four degrees, but only two, or two and a half; or when the two radii, being placed in an exact vertical line, seem to form a vertical line there exists in reality a slight degree of cyclophoria. In other words, in the measurement of this we must allow first for the normal outward tipping of each vertical axis of one and a half to two degrees, and then count any variation from that point as real cyclophoria.

In this connection it is necessary to clear up if possible some of the confusion existing in regard to the terms plus and minus cyclophoria. Several American writers define the term plus cyclophoria as a tendency of the upper end of the vertical axes to turn inward toward the vertical plane or beyond it, and minus cyclophoria, as a tendency to turn outward. The confusion produced by this definition is particularly unfortunate. For, as the upper end of the axis does tend to turn outward, as we shall see, in the act of convergence, any motion in that direction is naturally indicated by the plus sign. If these terms are to be retained at all, plus should indicate the turning of the upper end of the vertical axis outward from the normal position, and minus, a turning inward. To avoid ambiguity, however, it is better to use the words outward and inward from the vertical or from the normal position when that is specified.

The clinical importance of cyclophoria might be dwelt upon here, for as it is eminently a passive condition, the ocular muscles must make a corresponding effort to turn the vertical axes into the position which they normally occupy. In other words, a given degree of cyclophoria must always be accompanied by a corresponding effort of torsion. Any discussion of the clinical importance of torsion is, however, deferred until we study another aspect of the subject.

CHAPTER V.

BOTH EYES IN MOTION; AND FIRST GROUP OF ASSOCIATED MOVEMENTS.

§ 1. **Definition and Mechanism of Associated Movements.**—Our study of the motions of one eye alone has included much which relates also to the motions of both eyes. Thus, what we know concerning the action of one or more muscles moving one eye, applies as well to both eyes. This is also true of the rapidity of the lateral motions, of the field of fixation, etc., so that our study of the motions of both eyes is rather a study of their action together, or what is known as *associated* movements. In the introduction to his monograph on binocular vision, Hering (B 250) says that the two eyes may be regarded as the halves of a single organ. To the student of the ocular muscles this means that in order to avoid double vision, each eye acting with its fellow eye instinctively turns its visual axis to the point to which the attention is directed at that moment.

But by what mechanism can we explain the motor impulses which rotate both eyes in the same direction at the same time, as when we look from right to left, or again in opposite directions, as in convergence? Innumerable theories have been offered to account for this and, as usual, their number was in proportion to our ignorance of the subject. Gradually they have been discarded, however, as our knowledge of the functions of the cells in the nuclei and in different portions of the brain has grown more exact. At present there is considerable unanimity of opinion on the general propositions concerning the motor impulses and the routes by which they are sent from the gyrus angularis, or from the nuclei, to the eyes. The present condition of our knowledge is

shown in Bernheimer's (B 185) diagrammatic representation (Fig. 181). From this it appears that when a motor impulse

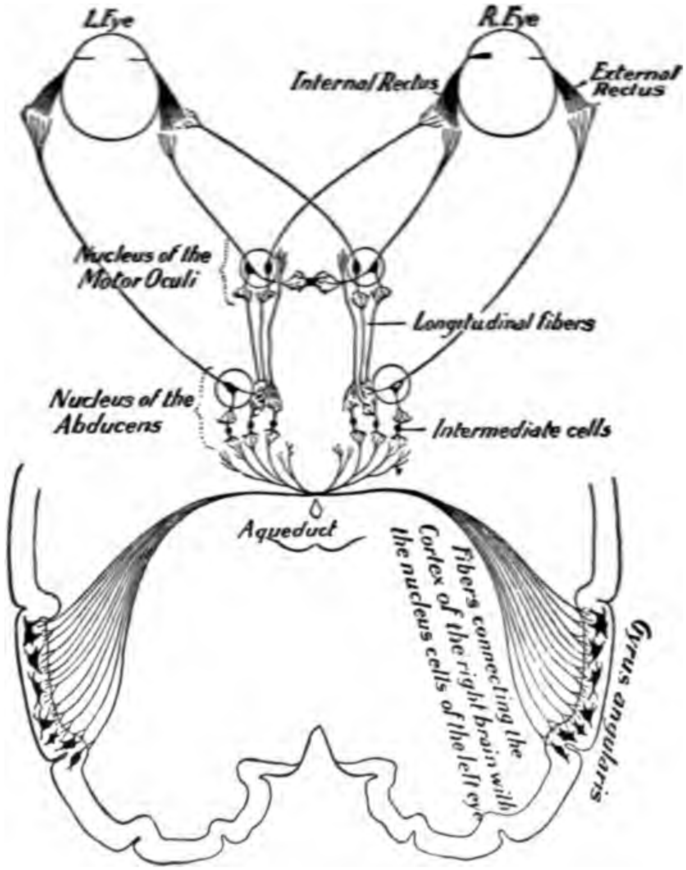


FIG. 181.—Diagrammatic representation of the cells which preside over **lateral** motions of the eyes and the fibers conducting the motor impulses (Bernheimer).

originates in the gyrus angularis on the right side, for example, that impulse crosses to the left side of the brain, communicating with the nucleus of the abducens and thence through to the external rectus of the left eye, while at the same time a part of the same impulse passes through the nucleus of the third nerve, and thence to the internal rectus of the right eye, causing both eyes to turn toward the left. Or an impulse for convergence may originate from the gyrus

angularis on the right side, and passing through the nucleus of the sixth may be continued to the nucleus of the third nerve, and from that point to each internal rectus. Or convergence may occur through an impulse originating in the cells which lie in the center of the nucleus of the third nerve. Undoubtedly this explanation of associated movements will be modified by further studies, but it accounts for the observed facts, perhaps better than any other. We do not know the details of the mechanism by which any of these associated movements are produced, but such facts as we have, tend to show that there are at least six conjugate innervations, one for each of the associated movements,—down, up, to the right, to the left, for convergence, and for torsion. These might be called the principal innervations. In addition, there are certainly several others—no one can say how many—to rotate the eye obliquely in various directions.

§ 2. **Classification of Associated Movements.**—These can be conveniently arranged in four groups.

1st. The parallel visual axes being in the primary position, the upper end of each vertical axis revolves about the visual axis[1] to the right or left, or they turn at the same time medianward or temporalward.

2d. The parallel visual axes move in one of the principal meridians to the right, left, up, or down. In this group of movements there is no torsion.

3d. The parallel visual axes move obliquely. In this group the vertical and horizontal axes *appear to change* their position in such a manner as to produce "false torsion."

4th. The visual axes do not remain parallel, but converge toward each other. In so doing, the upper end of each vertical axis rotates slightly outward producing "true torsion."

Strictly speaking, it is often neither the optic nor the visual axis about which a torsional movement is made, but one usually called the antero-posterior axis. For convenience, however, this being understood, it is better to speak only of the visual axis as the hub of the wheel motions. This outline of

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[1] As we can easily measure the angle alpha, the optic axis may be considered as practically the same as the visual axis.

the classification of the different associated movements indicates the plan to be pursued in their study. Each of these groups of movements is of importance in its way, and it is only for clearness of description that this sequence is followed.

§ 3. **First Group of Associated Movements.—Definition.** *The parallel visual axes being in the primary position, the upper end of each vertical axis revolves about the visual axis to the right or left, or they turn at the same time medianward or temporalward.* These motions are very limited and probably not of much importance clinically, but as the principles on which they depend must be considered in connection with the true torsion which accompanies convergence, it is well to understand what they are and how they are measured. At the outset we should appreciate clearly that what we are dealing with now is not cyclophoria, but a cycloduction. In order to determine the former, we found it was necessary first to dissociate the retinal images and then allow each vertical axis to rotate into the position most natural to it. Cyclophoria, like all the other phorias, is essentially *passive*, while the group of associated movements now to be considered are essentially *active* movements. They depend on the instinctive desire to fuse images which are not already entirely dissociated, but which fall on parts of the two retinas so nearly corresponding to each other that the muscles try to turn the globe so as to overcome, if possible, any double vision. Now when the muscles thus rotate the vertical (and horizontal) axes about the antero-posterior axes in the interest of single vision, we have a *torsion* or, as this is also called, a *circumduction* or a *cycloduction*. In a strict sense, the word "torsion" does not indicate whether the turning is of a passive nature (some form of a cyclophoria) or of an active nature (some form of circumduction or a cycloduction). The latter terms are in many ways preferable, because we are accustomed to use the termination "duction" to describe other motions which the globe makes in the interest of single vision. The fact is, however, that the terms "extorsion" and "intorsion" have been used so much as synonymous with different forms of cycloduction that it

seems better to keep this nomenclature until it is changed by the action of national or international ophthalmological societies.

In order to measure how far the muscles can thus rotate the globe in a wheel motion, we naturally try to devise some arrangement by which the image of a vertical line, for example, falls on one retina, and the image of a similar line not quite vertical falls on the other retina, and then observe to what extent the eyes are rotated, in order to fuse these lines. Such indeed was the plan followed even by the earliest students of this question. Thus we have:

(A) **Hering's Method** (B 586). The arrangement for this appears simple in theory, though its proper use requires a trained observer. On a blackboard which measures about 80 by 50 centimeters, two pieces of white string are attached as seen in Figure 182. Each of these is made

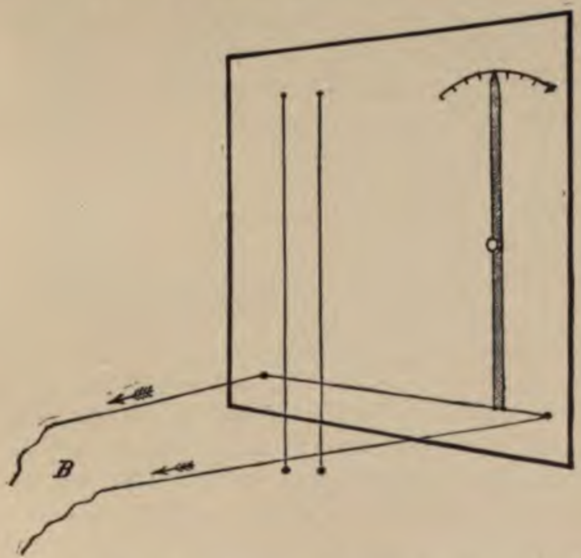

FIG. 182.—Hering's arrangement for measuring the position of the vertical axes.

taut by a bullet attached to the lower end. The distance between the two strings is about six centimeters. A little to

their right is a vertical red band of wood about two centimeters in breadth, attached to the blackboard by an iron pin passing through a hole in the center of the band in such a way that the band can be moved around the pivot to one side or the other, revolving in the plane of the blackboard. To the lower portion of this band another string is attached, one end of which passes horizontally to the right, through an eyelet on the blackboard, and the other end in the same manner to the left. The object of this string with its two long free ends is to allow the observer to tip the vertical red band more conveniently when he is at some little distance from the blackboard. The upper end of the vertical red band is pointed and moves along a graduated arc.

To make the measurement, the observer first steadies the head, preferably by resting his teeth on the wooden bar of a Helmholtz bit in one of its various forms (B 257, p. 657), and in doing so brings the left eye about opposite an imaginary vertical line between the weighted cords. The right eye is opposite the vertical band, and both are on a horizontal plane which passes through the pivot in the vertical band. If it is desired to ascertain the position of the vertical axes when the visual axes are parallel, of course the blackboard must be at a distance of at least five or six meters. The observer then looking steadfastly, as in the effort to obtain stereoscopic vision, endeavors to make the band appear between the two vertical strings. In order to accomplish this, it is often necessary to hold a sheet of cardboard or other screen vertically in the median line, having the cardboard so large that the right eye can see only the band, and the left eye only the vertical strings. Usually, in doing so, the upper end of the vertical axis of each eye actually turns a trifle outward. The observer then draws on the horizontal string which comes from the lower part of the band and tips the upper end of the band a trifle to the left. The distance which the upper end of the red band thus traverses in order to appear vertical indicates the amount which the upper end of the vertical axis of each eye has tipped outward.

Hering's method was the one used principally by Aubert and Landolt (B 820) in obtaining the data which will be dis-

cussed in connection with the torsion which accompanies convergence.

(B) **Donders's Method.**—Another early worker at this problem was Donders (B 590). His apparatus was simple, but necessitated a little care in having it perfectly leveled. The vertical lines, which in this case are represented by wires, are attached to a frame which moves over a second one.[1]

This apparatus he called an "isoscope." The principle involved is seen at a glance (Fig. 183), and the method of making these measurements is entirely similar to Hering's.

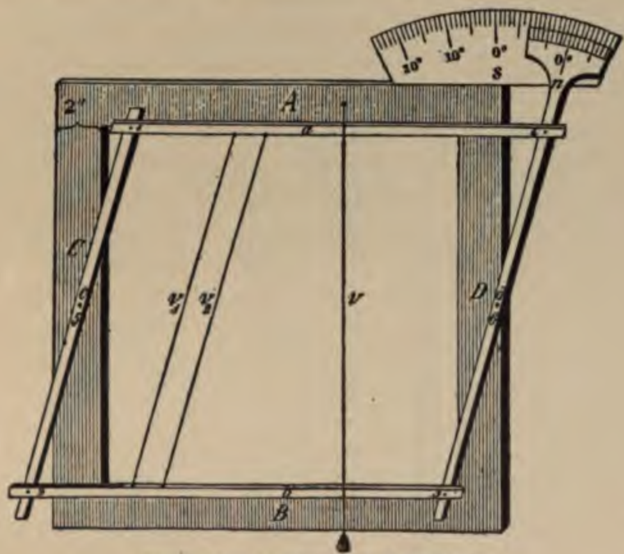

FIG. 183.—The isoscope of Donders.

(C) **Measurements of Torsion with Parallel Visual Axes by means of the Maddox rod.**—This rod can be made to produce a simple line on the retina, and as the tests which we are now considering depend on fusion of the images of such a line on each retina, it has been used by students for this purpose. Duane (B 558) refers to previous attempts of the kind, and describes the form which seemed to him best

[1] On attempting to verify these experiments it was found more convenient to dispense with one of the wires and to supplant it by a plumb line as shown in the figure.

adapted to such work. This consists briefly of two compound rods mounted on the frame which had been described by Stevens for his phorometer. The rod or series of rods before one eye is made of white glass, and that before the other of colored glass. When these two rods are placed horizontally, each one forms on the retina a vertical line. The power of fusion of the retinal images shows what degree of torsional power exists, the mechanical arrangement of Stevens's phorometer indicating with considerable exactness the amount of inclination which is given to each rod and therefore to the retinal images.

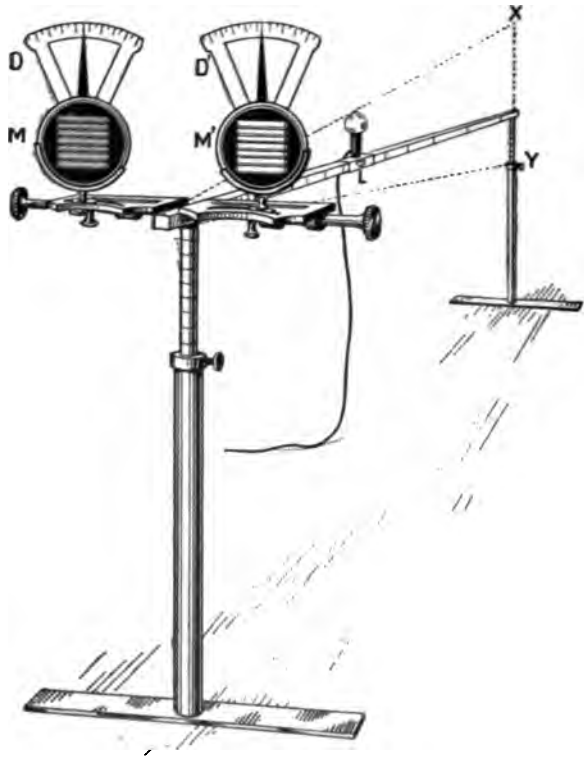

FIG. 184.—Arrangement by the author of the glass rods of Maddox for measuring torsion with parallel axes.

I have also found that the same principle can be used with advantage by slightly modifying a part of the apparatus

which is employed, as we shall see later, to measure relative accommodation, Fig. 184. In this a Maddox rod is placed before each eye, there being an index above to show the degree of inclination given to it. The source of light may be placed at a distance, or even approached within the usual five- or six-meter limit, for as each rod blurs the image of the flame, efforts at convergence are eliminated.

(D) Modifications of Volkmann's discs for the measurement of torsion with parallel visual axes. We have already seen that Volkmann's discs give the most accurate measurement of *cyclophoria* when one disc has a *radius* extending in one direction, and the other a *radius* in the opposite direction. In that form it constitutes the essential part of the clinoscope described by Stevens. In a similar way such discs can be used to measure *torsion* with parallel axes, provided we draw on each disc a *complete diameter* (Fig. 185). It is evident that such discs can be easily adjusted to any of the clinoscopes mentioned, and serve an excellent purpose.

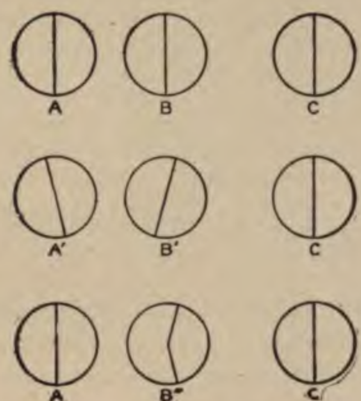

FIG. 185.—Diameters and radii used on Volkmann's discs.

In order to understand the difference between the measurements with the radii alone, and with the entire diameters when these are turned at an angle with each other, let us observe these discs of the clinoscope more carefully. In some descriptions of that instrument, each disc is figured with a vertical *diameter* as in A and B (Figure 185) Now it is known that if the upper end

of each of these diameters is revolved outward from the median line so that the diameters come to occupy such a position as we see in A' and B', then as each eye looks through one of the tubes of the clinoscope, the observer can still see one disc with one vertical diameter, as in C. Indeed, it makes but little difference whether each one of these vertical diameters is tipped outward or inward a certain number of degrees, or whether one of them remains vertical and the other is tipped out or in for a correspondingly greater number of degrees, they can still be fused into the one vertical diameter. This experiment can be verified either by the clinoscope, or by any similar arrangement of nearly parallel lines. But the explanation which is often given of this phenomenon is erroneous—at least in part. Thus it is said that when the upper end of either disc is tipped inward, then, in the interest of single vision, the corresponding eye rotates also. In this way it is supposed that the image of the line A, even when it is rotated to the position A', falls on a part of the retina which "*corresponds to*" the upper part of the image of the diameter in B' and for that reason—namely, because the images of the upper parts of the diameters in A' and B' fall on parts of the retina of the left and right eyes respectively which "correspond" to each other,—the images of those two lines are fused in the brain of the observer into one vertical line, such as he sees in C. This explanation is not entirely true. The experiment does not measure the amount of real wheel motion of the eyes, *if a whole diameter* of the disc be used. This can be easily shown. For, let us leave the vertical diameter A as it is, opposite the left eye, and before the right one, instead of the single diameter B, let us place a disc which has two radii bent at an angle to each other as in B". When the observer looks through the two tubes, *he can usually fuse the line A and the broken line B"* into one vertical line C. As it is evidently impossible for the right eye to turn in two directions at the same time, the only explanation of this result is that the upper and also the lower end of the broken line B" can each be made apparently to "correspond" with the upper and the lower ends respectively of the vertical diameter in A, even though these different points in the two eyes do not *actually* correspond with each other in any way. In other words, we must accept the view of Verhoeff, that what we call "corresponding points" in the retina is rather a relative term, and that points which do not anatomically correspond with each other can still be made to do so, within a certain small range, before double vision is produced.

§ 4. **Difference between "Maximum" and "Minimum" Extorsion or Intorsion.**—If, in any form of the clinoscope, a Volkmann's disc, with an entire diameter, is placed vertically before one eye, and a similar disc vertically before the other eye, and the two discs be fused into one, it will be found that one or both discs can be slowly rotated outward or inward five or six degrees or more, while the observer still sees but one disc. In other words, when the images are first fused, the instinctive desire to continue that fusion is sufficient to cause one eye or both to make a certain

"circumduction," or "cycloduction," or ex- or "in-torsion" as we prefer to call it. This is the *maximum* extorsion or intorsion, as the case may be. On the other hand, if the diameter on the disc before one eye is vertical, and the diameter before the other eye is turned outward, say eight, six, or even four degrees, the same person who before fused the two diameters at this point can not do so until they are brought very much nearer to the same position. In other words, when the retinal images are first dissociated, the muscles rotate the globe only a comparatively few degrees in the effort to fuse the two images. This may be termed the *minimum* power of intorsion or extorsion. Evidently in any examinations made with the Volkmann discs, this difference must be kept in mind.

§ 5. **The Physiological Amount of the Maximum or Minimum Extorsion or Intorsion** of which the eyes are capable when the axes are in the primary position has apparently not yet been determined by the examination of any considerable number of persons. Among the soldiers and students already referred to there was sometimes inability to fuse the discs at all, but in twenty-three non-asthenopic persons the tests were sufficiently accurate to be reliable. Among these it was found that with the eyes in the primary position there was an average minimum intorsion of about two and a half degrees and minimum extorsion of about four degrees. The number of persons is so small, however, as to serve only as an indication of what may be established. Maximum ex- and intorsion are often more than twice as much as the minimum, but vary greatly in different persons.

§ 6. **What Evidence is there that this Form of Torsion is of any Clinical Importance ?**—Many ophthalmologists are inclined to consider this rather a question of laboratory interest, or the fad of a few enthusiasts. Indeed, the study of torsion in any form has been much neglected because of extravagant claims concerning its importance and methods of treatment. As a result, the average practitioner is apt to class all together and consign them to oblivion. But a simple experiment with the Volkmann discs is sufficient to show the pathological effect of even small variations in the

amount of torsion. Thus, when with parallel axes the minimum intorsion is about three degrees, if the discs be adjusted to a slightly greater number of degrees and kept there even for a few minutes, the sense of discomfort is very marked and by persistence becomes extremely annoying. But this is nothing more than the condition, in some cases at least, in certain forms of astigmatism where the axes are sufficiently near to each other to permit a constant effort on the part of the individual to fuse the retinal images. If such a person focuses vertical lines clearly with one eye, and if with the other eye, when making the same effort at accommodation, he naturally focuses lines which are slightly oblique, we would expect him to make the same effort at torsion as occurs when such lines are viewed on the Volkmann discs. In fact, that is just what we do find not infrequently. The evidence is abundant that when the axes of astigmatism approach each other, but are still sufficiently divergent to produce this effort at torsion, that condition is a very important cause of asthenopic symptoms, even though the degree of astigmatism be slight.

This phase of the subject will be elaborated in a subsequent chapter.

CHAPTER VI.

SECOND GROUP OF ASSOCIATED MOVEMENTS.

Definition. *The parallel visual axes move in one of the principal meridians to the right, left, up, or down. In these movements there is no torsion.* This is shown by very simple experiments with after-images, according to the plan which was first suggested by Ruete. They are more easily followed if we confine our attention to the vertical axis of one eye only.

If we wish to ascertain what position the after-images assume when one eye moves (and the other one moves with it) in any one of the principal meridians, we do not require to have before us any surface mapped off exactly. One of the simplest methods of obtaining a vivid after-image, and one which serves our purpose in this case, is to allow the sunlight to enter a dark room through a narrow slit.

Let us suppose that we wish to ascertain what changes appear in the after-image of a vertical slit when parallel visual axes move in the principal meridians. The observer sits opposite a vertical slit in a shutter, and if the sun is shining brightly, in a few seconds the image of the slit is branded on the retina. Now if the eye be turned straight up and down, the after-image of the slit remains vertical. It often happens, in making this experiment, that as the eye moves up and down, for example, the vertical after-image seems to be vertical, but moves somewhat obliquely up and down. This is because the head is not held perfectly straight, and by tipping it a little to one side or to the other it is easy to see that there is no change in the direction of the vertical axes as the eyes make this movement. If the vertical line in the shutter is changed to one which is horizontal, movements of the eyes from side to side give similar

results. We establish for ourselves in this way the fact that in these associated movements of the second group the vertical axes remain practically vertical, and the horizontal axes remain horizontal. The clinical bearing of this fact is evident in connection with the position of the double images which accompany paralyses.

CHAPTER VII.

THIRD GROUP OF ASSOCIATED MOVEMENTS.

§ 1. **Definition.**—*The parallel visual axes move obliquely. In this group the vertical and horizontal axes apparently change their positions in such a manner as to produce "false torsion."* This movement from a primary to a secondary position is illustrated in Figure 186. Thus, if the anterior end of the

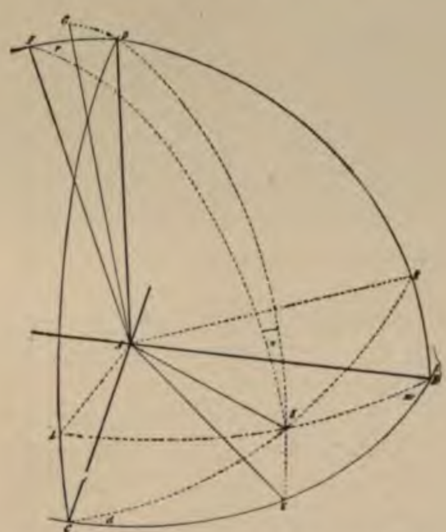

FIG. 186.—Arc described when the visual axis A B passes from the primary into some secondary position—for example, to E (Meissner).

visual axis passes from the point B, in the primary position, to the point E, the changes produced are the same as though the eye reached that position first, by passing to the point K and then upward to E, or from B to H to

E, or through any other point, no matter where it is situated, to the point E.

Now, in any movement of this group, what we call the vertical axis at one instant, ceases to be the vertical axis as soon as the globe has changed its position. The result is an apparent rolling of the globe, though not a true wheel motion. With proper precautions, this can be seen in the movement of a given spot in the iris.

This movement was first described simply as "torsion" or "Rollungen" by Helmholtz (B 584) and by Donders (B 590), while Maddox (B 263) and some of the other English writers properly call it "false torsion," to distinguish it from the true wheel motion. Objectively, or as far as the motion is concerned, false torsion is a twisting motion, if it might be so called, about the antero-posterior diameter, though of course there is no twisting of the globe as a rope is twisted. Subjectively, it is the distortion which

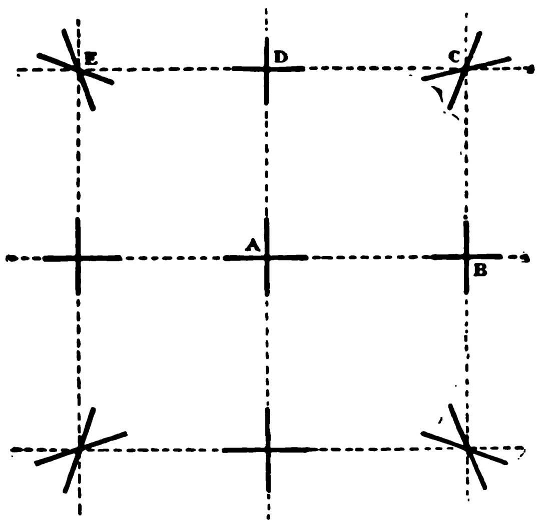

FIG. 187.—Position which the after-images assume when projected on a flat background (Listing).

an object seems to undergo when that object is viewed on a *flat* surface, like a wall.

The facts with regard to false torsion can be studied

best by means of the after-images. If we wish to determine accurately the amount of tipping which after-images undergo, it is necessary to have a suitable background as a measure

FIG. 188.—Curves of which the after-images form a part.

upon which those images can be projected. Such a background cannot be easily distinguished in a darkened room, and we must therefore modify the plan followed when studying the last group of associated movements. On a well-illuminated white wall about one meter square, or, still better, on a piece of enameled cloth, we draw cross lines in black such as are represented in Figure 187. At the center we attach a cross (A) of bright red ribbon, about ten centimeters long and one centimeter broad. With this white surface well illuminated and the center of the cross about on a level with the eyes, and with accommodation well relaxed, let the chin of the observer rest on a suitable support, so that the head is easily retained in the same position. Then, after looking intently at the central cross long enough to brand its image upon the retina, it is well first to turn the

eye straight up or down, and the after-image should slide along the vertical meridian on which the red band is drawn. Or if not, it can be made to do so by tipping the head slightly, or turning it from side to side in order to bring the head into just the vertical position.

After having thus adjusted the position of the head with reference to the vertical, and in a similar manner to the horizontal planes, the visual axes can be directed obliquely. When that is done, however, it is noticed at once that, as the after-image is projected on the flat wall in front, the cross no longer remains a perfect cross, but seems to be distorted, and this distortion increases in proportion as the point looked at, is distant from either the horizontal or the vertical meridian. Indeed, with a little practice it is easy to see that the increase in the amount of distortion is dependent upon two factors. One of these is the distance of the point looked at from the horizontal meridian, and the other is its distance from the vertical meridian. It is well to note this fact, because it forms the basis of all the calculations concerning false torsion. The position which the arms of the cross assume is seen in Figure 187. It is not easy to keep in mind what these positions are, but they will be recalled easily if we remember that the distorted cross would form part of the curve if the vertical lines curved inward toward the central cross, and the horizontal lines also curved toward the cross, as seen in Figure 188.

The foregoing changes in the position of the after-images when the axis is in an oblique position are those seen, as we must remember, when the images are projected on a *flat* surface. It is these images which were studied by the earliest writers, and from them most of the conclusions were drawn concerning the corresponding changes which the eye also was supposed to undergo when assuming an oblique position. But the important fact is that the position of the lines of the cross are distorted only because they are projected upon the flat surface.

Tscherning (B 645) made a complete and beautiful demonstration of this fact. He constructed a hemisphere of considerable size, and placing the head at its center, he looked

at the cross immediately in front until its image was impressed on the retina, and then turning the eyes in various oblique directions, he found the after-images were not exactly the same as the after-images projected on a flat wall, but appeared as in Fig. 189.

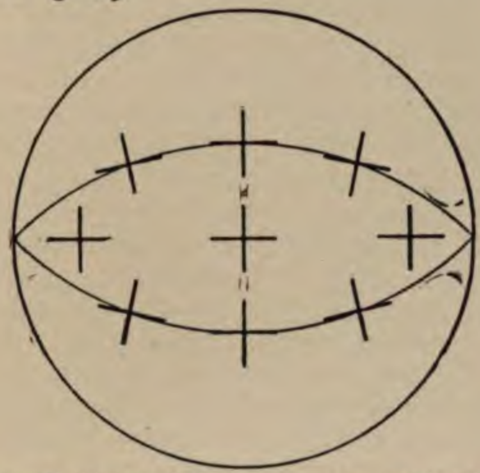

FIG. 189.—Position which the after-image assumes when the cross is projected on the concave surface of a hollow hemisphere (Tscherning).

§ 2. **This Form of Torsion is not a True Wheel Motion.** —In order to obtain a clearer idea of the motions of this group, let us make use of an ophthalmotrope in some one of its forms. Take, for example, the simple rubber ball transfixed by three needles and add to it as follows:

1st. Attach a fine thread to the anterior polar axis as it emerges from the globe. Make this thread a little longer than the radius of the circle which represents the cornea, and to the loose end of the thread attach a small bead, a bit of shoemaker's wax, or some other object heavy enough to make a plumb line of it.

2d. Mark off about thirty or forty degrees at the lower edge of the circle which indicates the edge of the cornea, or any other circle on the eye concentric with it.

3d. Transfix the rubber ball with still another knitting needle, which shall constitute the axis upon which the globe revolves into the oblique position to which it is to turn.

If we prefer to use for this purpose the more complete

ophthalmotrope, it is only necessary to attach to the front part of the globe a projecting point which represents the anterior end of the polar axis; the graduation near the edge of the cornea is already marked, and by changing the position of the radial pins we allow the globe to turn into almost any position desired.

When the visual axis passes up and outward, for instance, the plumb line shows that what was the vertical axis in the primary position no longer remains so, but that another axis which marks another vertical plane has taken its place. The number of degrees between these two plumb lines marks evidently the amount of, or the angle of false torsion. But during this act the globe has not really revolved directly upon the visual axis. In other words, this form of so-called torsion is only a result of two motions which the globe has made out and upward. Later we will consider more exactly how the exact amount of this torsion can be calculated, but at present let us continue with the question immediately before us—namely, the nature of the motion itself.

This can also be illustrated very readily by a simple circular disc of cardboard, as suggested by Le Conte (B 825, p. 198) and elaborated by Maddox (B 263, p. 47).

The former says: "A simple experiment will show the kind of rotation which takes place in bringing the eye to an oblique position. Take a circular card (Fig. 190) and make on it a rectangular cross, which shall represent the vertical (VV) and horizontal (HH) meridians of the retina. A small circle p represents the pupil. Now take hold of the disc with the thumb and finger of the right hand at the points VV, and place this line in a vertical plane. Then tip the disc up so that the pupil p shall look upward 45° or more, but the line VV

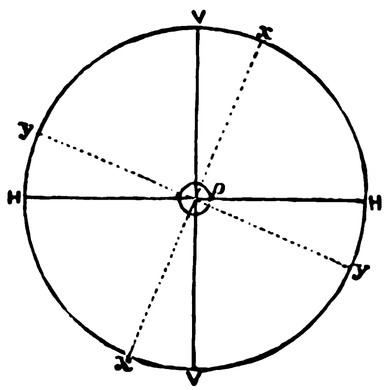

FIG. 190.—Cardboard model to illustrate false torsion.

still remaining in the vertical plane. Finally, with the finger of the left hand, turn the disc on the axis VV to the left. It will be seen that VV is no longer vertical, nor HH horizontal, but some other line—*XX*—is vertical and *YY* horizontal. In other words, the whole disc seems to have rotated to the left. But there is evidently *no true* rotation on a polar axis, but only an *apparent* rotation consequent upon reference to a new vertical meridian of space."

There is often so much confusion concerning this point that it is worth while thus to vary the illustration, even at the risk of tedious repetitions.

§ 3. **Conclusions Regarding the Data Obtained by these Experiments with the After-Images.**—At this point it is desirable to review the data which we have collected from these experiments and to summarize in as few words as possible the conclusions to which we have been led. We can then see how these conclusions of our own compare with the more condensed statements concerning the same motions which have been given by others, and which have come down to us in the literature as the laws of Donders and Listing. We have found:

1st. When the eye moves from the primary position, up, down, right, or left, as in movements of the second group, no torsion occurs.

2d. When the eyemoves into an oblique position the axis which is vertical in the primary position is supplanted by another vertical axis, the former vertical axis being then oblique.

3d. The after-images which we see projected on a fla; surface are not in the same position when projected on a concave surface to which the visual axis is perpendicular.

4th. This so-called false torsion is not a true wheel motion of the globe.

§ 4. **Donders's Law.**—With these conclusions before us it is easier to understand the more exact "laws" or statements concerning these movements which have been formulated by Donders and Listing.

First, as to Donders's law. This is usually stated by saying that "the wheel motion of each eye with parallel

fixation lines is a function only of an elevation and of a lateral deflection." Donders's law is therefore only another way of stating what we have seen with the after-images of the cross on the squares—namely, that the amount of this false torsion depends on two factors,—the number of degrees which the visual axis turns up or down, and the number of degrees which that axis turns in or out.

§ 5. **Listing's Law.**—According to this, "when the line of fixation passes from its primary to any other position, the angle of torsion of the eye in this second position is the same as if the eye had arrived at that position by turning about a fixed axis perpendicular to the first and second positions of the line of fixation."

The fact is that Listing did not formulate that law at all. He gave the principle, and later, in 1853, Ruete gave the words,—unfortunately, obscure ones. For as Mauthner observed, "simple as this law is, and as it sounds, certainly no one ever understood it at first hearing." It is doubtless a source of consolation to most of us to know that a man long trained in problems of physiological optics also finds this condensed statement difficult to understand. Yet Listing's law only expresses in another way what we have seen already in these experiments with after-images of the cross. Concerning this subject, Tscherning says: "The law of Donders may be considered as undergoing further development in the law of Listing. The former indicates *how* the position of the after-image is determined by a given position of the visual axes; the latter tells us *what* that position is."

§ 6. **Calculation of the Amount of Torsion with Parallel Axes.**—Having thus seen what torsion with parallel visual axes is, how it is produced, and how it can be illustrated objectively, we will follow it one step further to ascertain its exact extent with any given position of the visual axis. This was calculated by Helmholtz (B 257, p 624) and most of the following table was published in his *Physiological Optics.* His table, however, was not carried quite far enough to show the torsion which occurs with certain movements up or

down, which are quite common. It has therefore been extended and in the elaborated form is as follows

In or out	Up or down.								
	5°	10°	15°	20°	25°	30°	35°	40°	45°
5°	0° 13′	0° 26′	0° 40′	0° 53′	1° 07′	1° 20′	1° 35′	1° 49′	2° 04′
10°	0° 26′	0° 53′	1° 19′	1° 46′	2° 13′	2° 41′	3° 10′	3° 39′	4° 09′
15°	0° 40′	1° 19′	1° 59′	2° 40′	3° 21′	4° 02′	4° 45′	5° 29′	6° 15′
20°	0° 53′	1° 46′	2° 40′	3° 34′	4° 29′	5° 25′	6° 22′	7° 21′	8° 21′
25°	1° 07′	2° 13′	3° 21′	4° 29′	5° 38′	6° 48′	8° 0′	9° 14′	10° 30′
30°	1° 21′	2° 41′	4° 02′	5° 25′	6° 48′	8° 13′	9° 39′	11° 08′	12° 40′
35°	1° 35′	3° 10′	4° 45′	6° 22′	8° 0′	9° 39′	11° 21′	13° 06′	14° 53
40°	1° 49′	3° 39′	5° 29′	7° 21′	9° 14′	11° 08′	13° 06′	15° 05′	17° 09′

§ 7. Aids to the Calculation of Torsion with Parallel Visual Axes.

As this calculation is not a simple one, and as some student of mathematical turn may care to direct his energies toward the solution of the problem, one or two hints may prove acceptable. The best-known formula is the one given by Helmholtz (*Physiologische Optik* second edition). In this α is the vertical movement, β the lateral movement, and γ is the size of the angle of rotation.

$$-\tan\gamma = \frac{\sin\alpha \sin\beta}{\cos\alpha + \cos\beta}$$

From which, as Helmholtz says, "there follows"

$$-\tan\left(\tfrac{\gamma}{2}\right) = \text{tang}\left(\tfrac{\alpha}{2}\right)\,\text{tang}\left(\tfrac{\beta}{2}\right)$$

Most students will not be able to see at a glance how this second equation "follows" from the first one, and the intermediate steps are therefore given.

In the formula understanding that A is equal to Alpha, B is equal to Beta, G is equal to Gamma, then

$$\tan G = \frac{\sin A \sin B}{\cos A + \cos B} \Leftrightarrow \tan \tfrac{1}{2} G = \tan \tfrac{1}{2} A \tan \tfrac{1}{2} B$$

$$\cos^2 G = \frac{1}{\tan^2 G + 1} \text{ (2) derived from trig. form. } \sec^2 G = \tan^2 G + 1$$

$$\tan^2 G = \frac{\sin^2 A \sin^2 B}{\cos^2 A + 2\cos A \cos B + \cos^2 B}\text{. Substituting in (2)}$$

$$\cos^2 G = \frac{1}{\dfrac{\sin^2 A \sin^2 B + \cos^2 A + 2\cos A \cos B + \cos^2 B}{\cos^2 A + 2\cos A \cos B + \cos^2 B}}$$

$$= \frac{\cos^2 A + 2\cos A \cos B + \cos^2 B}{\sin^2 A \sin^2 B + \cos^2 A + 2\cos A \cos B + \cos^2 B}\text{.}$$

Substituting for $\sin^2 A$ and $\sin^2 B$ their equals. $1 - \cos^2 A$ and $1 - \cos^2 B$

$$= \frac{(\cos A + \cos B)^2}{1 - \cos^2 A - \cos^2 B + \cos^2 A \cos^2 B + \cos^2 A + \cos^2 B + 2\cos A \cos B}$$

$$= \frac{(\cos A + \cos B)^2}{1 + 2\cos A \cos B + \cos^2 A \cos^2 B}$$

$$\cos^2 G = \frac{(\cos A + \cos B)^2}{(1 + \cos A \cos B)^2}$$

$$\cos G = \frac{\cos A + \cos B}{1 + \cos A \cos B}$$

$$1 - \cos G = \frac{1 + \cos A \cos B - \cos A - \cos B}{1 + \cos A \cos B}$$

$$1 + \cos G = \frac{1 + \cos A \cos B + \cos A + \cos B}{1 + \cos A \cos B}$$

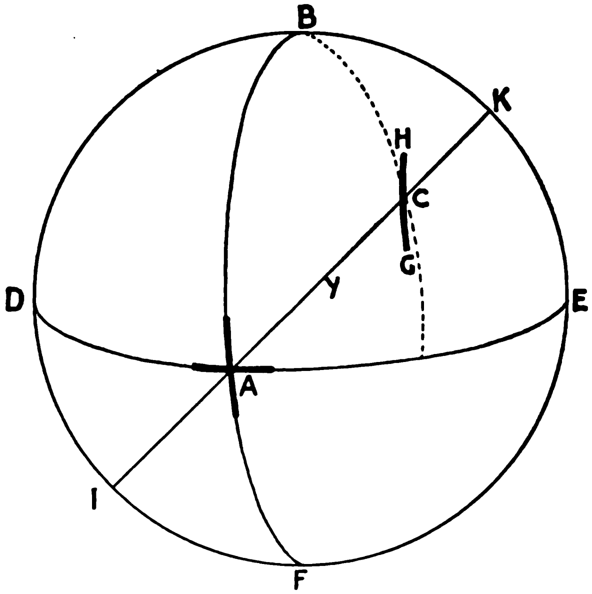

FIG. 191.—Anterior view of the globe showing the position which the vertical arm of the cross assumes when the eyes pass from the primary to a secondary position.

$$\frac{1 - \cos G}{1 + \cos G} = \frac{1 + \cos A \cos B - \cos A - \cos B}{1 + \cos A \cos B + \cos A + \cos B} = \frac{(1 - \cos A)(1 - \cos B)}{(1 + \cos A)(1 + \cos B)}$$

$$\tan^2 \tfrac{1}{2} G = \tan^2 \tfrac{1}{2} A \tan^2 \tfrac{1}{2} B$$

$$\tan \tfrac{1}{2} G = \tan \tfrac{1}{2} A \tan \tfrac{1}{2} B$$

Another and quite different method of calculating the amount of torsion with parallel visual axes has been suggested to me by Mr. W. C. Krathwohl and is as follows:

If we were to take any point on the cornea, Fig. 191, and let it move in every possible direction, it would describe a sphere ABEFD. Let BAF be an

anterior-posterior vertical meridian; also, let us suppose that a cross is marked upon the eye, and that it moves from A to C. If the eye were to move so that there were no torsion, the vertical arm of the cross would lie on the meridian BC but since the eye moves so that the cross keeps parallel to its former position, it assumes the position HG, and the angle HCB equals the angle of torsion.

$$\text{Angle HCB} = \text{angle HCA} - \text{angle BCA}$$

But since HC is parallel to BA, and IC is a continuation of AC, therefore

$$\text{angle HCB} = \text{angle BAI} - \text{angle BCA}$$

If we let the angle of inclination of the axis of movement to the meridian DAE be denoted by x, and the degree of rotation by y, then

$$\text{angle CAE} = x = \text{DAI and angle BAI} = 90^\circ + x$$

Therefore,

$$\text{angle HCB} = 90^\circ + x - \text{angle BCA}$$

In order to find angle BCA we must solve the triangle BAC, in which BA $= 90^\circ$, AC $= y$, and angle BAC $= 90^\circ - x$

In order to solve this triangle we must first solve its polar triangle B′ C′ A′, Fig. 192, in which

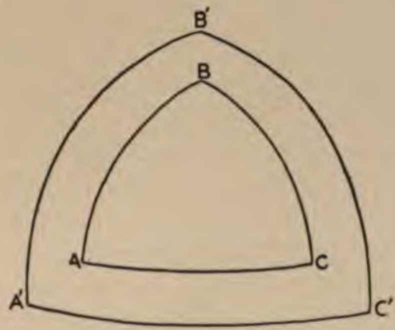

FIG. 192.—Triangle for the calculation of the position of the images in false torsion.

$$\text{angle } C' = 180^\circ - AB = 90^\circ$$
$$\text{angle } B' = 180^\circ - y,$$
$$B'C' = 180^\circ - (90^\circ - x) = 90^\circ + x$$
$$\text{Cos angle } B' = \frac{\tan B'C'}{\tan A'B'}$$
$$\text{Tangent } A'B' = \frac{\tan B'C'}{\cos \text{angle } B'}$$

Substituting for A′ B′, B′ C′, and angle B′ their respective equals $180^\circ - \text{BCA}$, $90^\circ + x$, and $180^\circ - y$

$$\text{tangent}\,(180^\circ - \text{BCA}) = \frac{\tan(90^\circ + x)}{\cos(180^\circ - y)}$$
$$-\text{tangent BCA} = \frac{-\cot x}{-\cos y} = \frac{\cot x}{\cos y}$$

But in Figure 191, since

$$\text{angle HCB} = 90^\circ + x - \text{angle BCA}$$

therefore

$$\text{angle BCA} = 90^\circ + x - \text{angle HCB}$$

$$-\text{tangent BCA} = -\tan(90^\circ + x - \text{angle HCB})$$

$$= \cot(x - \text{angle HCB}) = \frac{\cot x}{\cos y}$$

$$\frac{1}{\tan(x - \text{angle HCB})} = \frac{1}{(\tan x)(\cos y)}$$

$$\tan(x - \text{angle HCB}) = (\tan x)(\cos y)$$

§ 8. **The Clinical Importance of False Torsion.**—Why is it advisable to devote so much space to the consideration of torsion in this form, or indeed in any form?

First. It is to clear up, if possible, some of the obscurity which shrouds this point in the minds of most students and it is hoped that the attempt has been at least partially successful.

Second. The relation of this form of torsion to the positions of the double images seen in certain cases of paralysis is sometimes important.

It is easy to understand how any imperfect movements of the globe will not only distort but may displace the images of distant objects, and a clearer understanding of the normal changes helps us to comprehend those which are abnormal. At present only a single example of this need be given.

Let us select one of the simplest types—that of a paralysis of the sixth nerve on the right side. In that case the axis of vision of the right eye turns toward the left side and we have homonymous double images toward the right. The image with the left eye is of course in the normal position. If the patient be directed to look at a vertical object in front—a candle, for example,—the image of that candle which is seen with the right eye, like the arm of the cross used for experimenting with after-images, remains vertical, just as does the after-image when the visual axis passes straight up or down. In other words, in these principal meridians there is no torsion.

But when the candle is moved upward and to the right, the image which is seen with the right eye is no longer vertical, the upper end being tipped more or less away from the

median plane. The tendency of the eye is toward the same kind of torsion which it undergoes when not paralyzed. When, however, in the latter condition it acts more or less independently of the other eye, then the tipping which the corresponding image of the candle undergoes when in this oblique position depends evidently upon three factors. The first two are stated in Donders's law, and worked out exactly in the table by Helmholtz, being the amount which the eye turns upward and then out, or outward and then up, as the case may be. The third factor is the degree of paralysis which is present in the individual case. This, with the other two, determines the amount of inclination given to the false image of the candle.

CHAPTER VIII.

THE FOURTH GROUP OF ASSOCIATED MOVEMENTS. CONVERGENCE.

Definition.—*The visual axes do not remain parallel ut converge toward each other. In doing so, the upper end of each vertical axis rotates slightly outward, producing true torsion.*

This group of motions is evidently the most important with which we have to deal, because convergence is accompanied normally by a certain amount of accommodation and also of true torsion. In order to take each step securely in this part of our study, it is desirable to make a digression here, that we may review briefly our data concerning prisms and the more fundamental questions relating to convergence. After that we can pass to the relation of convergence either to accommodation or to torsion.

DIVISION I.

Ophthalmological Prisms.

§ 1. **Definition.**—An ophthalmological prism is a wedge of glass having at least two polished surfaces which meet at an angle. This is called the angle of refraction. The optical properties of a prism are illustrated in Figure 193. The principle involved is the elementary one in optics, that when a ray of light passes from one medium into another which is more dense, the ray is bent toward a plane perpendicular to the surface of the denser medium. The reverse, of course, obtains if the ray passes from a medium which is dense to one more rare.

When a prism is placed with its angle of refraction toward the nedian line, it is called an *adductive* prism. In this posi-

tion it is also known as a minus prism, for if extended to meet a corresponding prism before the other eye, the two together would have in their refraction an effect analogous to that of a concave or minus glass. When, however, the angle is toward the temple, it is called an *abductive* or a plus prism.

§ 2. **Numbering of Prisms.**—As different methods of numbering prisms have been in vogue at different times, it is necessary to understand what is referred to when they are mentioned. They have been numbered:

(A) According to the size of the refracting angle. This is a convenient method, but evidently inaccurate, as a prism

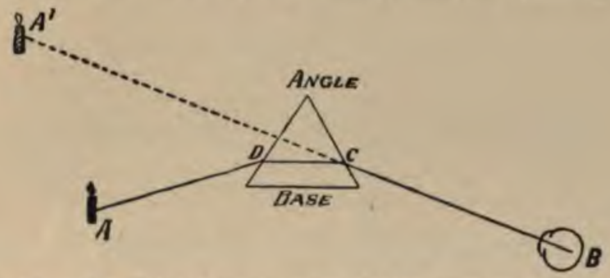

FIG. 193.—The ophthalmological prism and the displacement of the image which it produces (Hansel).

made from glass which has a high index of refraction must differ materially from another made from glass of a lower index. This method therefore has been to a great extent discarded, though still employed by some European manufacturers.

(B) A much more exact method was proposed by Dennett (B 709), according to what he termed the "centrad," that being a deviation whose arc is one one-hundreth ($\frac{1}{100}$) of the radius. Although perfectly exact and entirely in accord with similar mathematical calculations, this method of numbering prisms has not been very generally adopted.

(C) Another method of numbering is according to the so-called "prism-diopter" of Prentice (B 712). That is, according to the amount of displacement which a prism would produce when held at a distance of one meter from a given object. Thus if a meter measure is placed horizontally on

the wall, and the observer, standing opposite its right-hand end and at a distance of one meter, looks at that end of the measure through a prism with its refracting angle toward his left and in the position of minimum deviation, then, if the displacement produced amounts to three centimeters, the prism would be called No. 3. If it produced a displacement of five centimeters it would be called prism No. 5, and so on.

In reality, a prism whose refracting angle measures 3 degrees with the goniometer, does not produce a minimum deflection of exactly 3 centimeters when placed at a distance of one meter from the object. The difference, however, is very slight, and we are evidently safe in adopting the "prism-diopter" method of numbering prisms as the most practical.

For convenience in testing, suitable scales have been arranged like the one suggested by Zeigler (B 722), of Philadelphia.

The following table from Jackson shows at a glance the relation of the refracting angle and the prism-diopters to the centrad.

ANGLE.	CENTRAD.	PRISM-DIOPTERS.	ANGLE.	CENTRAD.	PRISM-DIOPTERS.
1.06	1	1.	9.39	9	9.02
2.12	2	2.	10.39	10	10.03
3.18	3	3.	11.37	11	11.03
4.23	4	4.	12.34	12	12.04
5.28	5	5.	13.29	13	13.06
6.32	6	6.01	15.16	15	15.11
7.35	7	7.01	19.45	20	20.26
8.38	8	8.02	36.03	50	54.62

Burnett (B 714, 715, 723), who wrote on this subject quite extensively, says that the practical value of the prism-diopter is demonstrated by the fact, probably not generally known, that all the prisms manufactured in the United States since 1895 have been measured and numbered by the prism-dioptral system, and, whether we recognize it or not, we are using prism-diopters in our work every day, even though we may order our prisms in degrees or centrads. If foreign manufacturers would adopt the same plan, this discussion of differences would become unnecessary.

§ 3. **In What Forms are Prisms Arranged or Combined**

with Each Other?—The simplest of all is the single prism. The effect of this has already been described, but as it is difficult to adjust this accurately in a circular frame, some practitioners prefer square prisms set in square frames (Fig. 194).

As it was found to be slow and annoying to reach to the trial case for each separate prism, Noyes placed them in series. Sometimes they are made as in Fig. 195, or still more conveniently arranged in a series of about twenty together. (Fig. 196).

As single prisms had thus been placed side by side in every conceivable order, another principle was brought into use, and has also undergone various modifications. This is to revolve one prism before another in such a way as to

FIG. 194.—Frames for square prisms.

obtain a greater or less refractive effect. Probably the first one to adopt this plan for clinical purposes was the French optician Creté, but the mechanical part of that contrivance was rather cumbersome, so Risley used instead two small prisms in a frame which could be placed in the trial case, but which rotated one before the other in a similar manner (Fig. 197). To obtain a slower increase of weaker effects, Jackson added still a third prism (Fig. 198). In this category should be placed also the two prisms which we find in the arrangement suggested by Stevens, and called by him a phorometer. Here the two prisms are not placed directly upon one another, but one rotates before each eye. The principle involved, however, is the same. In that instrument a prism of eight degrees is placed, with the apex up, before one eye, and before the other eye is another prism in the reverse position. By a simple cog arrange-

ment, each is made to turn so that the refracting angle points upward, outward, or in any direction desired. While this is an extremely convenient arrangement for determining the static condition of the eyes, as we have seen, on the

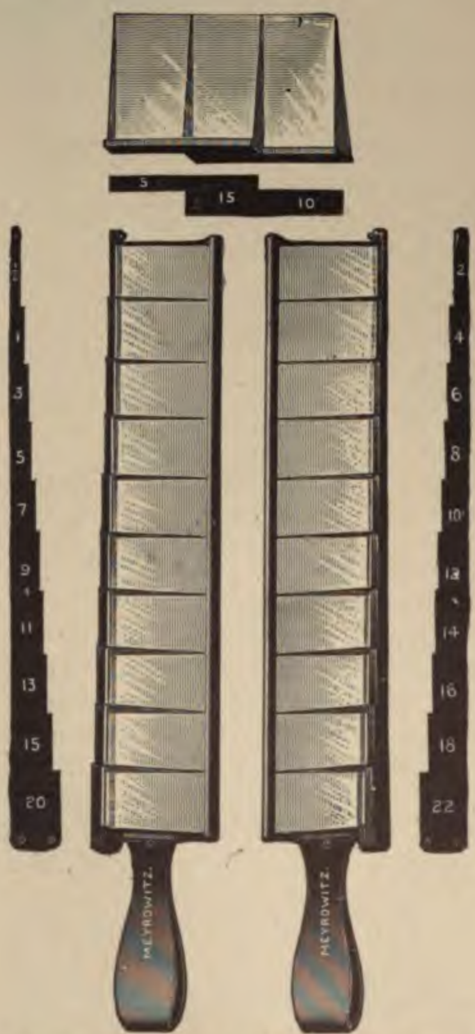

FIG. 195.—Horizontal prisms in series (Noyes).

FIG. 196.—Series of prisms as used by the author.

other hand the prisms are not sufficiently strong for testing the dynamic condition often found.

§ 4. **Results Produced by the Combination of Prisms.**—Of course it is easy to increase the strength of prisms by adding one to another, keeping base to base and apex to apex. Thus two of four degrees each, applied one on the other in this manner, give us for practical purposes one prism of eight degrees, or by reversing their direction the two prisms exactly neutralize each other.

The question is more complicated, however, when we wish to know the resultant strength of one such prism revolved at a given angle. Here we are brought at once to a formula which it is convenient to have for reference, because the calculations deduced from it give us the markings which we find on all revolving prisms, including those on the phorometer. The following calculation is given in full because it is proper to show how this important formula is obtained, and also because the method here followed is apparently new.

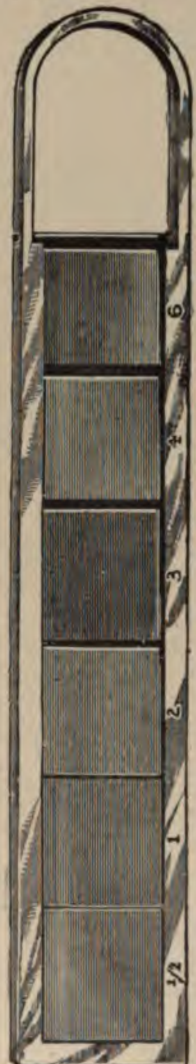

FIG. 197.—Vertical prisms arranged in series, (natural size.)

Let the angle at the apex of the prism (Fig. 199) which is to be revolved be denoted by P, and the angle through which the prism revolves by R. It is assumed that the prism is revolved in such a manner that its edges af, ib, and cd describe planes perpendicular to the plane in which we wish to measure the component of refraction. It is also assumed for the sake of convenience that we are dealing with a right-angled prism, and that the right angle is formed by the planes ci and ab, and that the three edges ji, eh, and af of the prism are parallel. Let us now imagine the revolving prism rotated from its horizontal position on the point f in space as an axis, where the apex af is perpendicular to the plane in which we wish to measure the component of refraction. If then we conceive this plane as marking off a section of the prism it would

mark a triangle which, when revolved to the position in which we wish to measure the equivalent prism, is the triangle jfe. Since the plane of the triangle is perpendicular to af, the lines fj and fe, in the planes aj and ae, measure the angle of the prism; hence the angle jfe = P.

We now revolve our prism to the position in which we desire to find an equivalent prism, and then let the plane in which we propose to measure the component of refraction again pierce the prism. It will cut a triangle hfi. Let us suppose that we now pass planes through the lines fi and hf, and that these planes are perpendicular to the plane in which we desire to measure the component of refraction; then we have here a prism whose actual plane of refraction coincides with the plane in which we are going to measure the component of refraction, hence our revolving prism in its position is equivalent to this new prism and all we must do is to measure the angle hfi at its apex, which we shall call P^1. Furthermore, the angle jfi through which the prism has revolved, we shall call the angle R. Since the planes in which the lines bi and ch revolve are perpendicular to our plane of refraction, je and hi, which lie in the same plane, are perpendicular to bi, hence they are parallel, and since eh and ji are parallel, je and hi are equal. Furthermore, the angles ejf and hif are right angles.

FIG. 198.—Rotating prisms (Risley)

$$\sin P = \frac{je}{fe}, \text{ hence } je = fe \sin P$$

$$\cos R = \frac{fe}{fh}, \text{ hence } fh = \frac{fe}{\cos R}$$

$$\sin P' = \frac{hi}{fh}$$

Substituting for hi its equal je,

$\sin P' = \frac{je.}{fh}$ Substituting for je and fh their respective values,

$$\sin P' = \frac{fe \sin P}{\frac{fe}{\cos R}} = \frac{fe \sin P \cos R}{fe} = \sin P \cos R.$$

$$P' = \sin^{-1} (\sin P \cos R)$$

In like manner if we denote by R′ the angle through which the other prism revolves from the plane in which we wish to measure the component of refraction, by Q the angle of the apex of the prism, and by Q′ its equivalent angle after rotation, then

$$Q' = \sin^{-1} (\sin Q \cos R')$$

Denoting by S the sum of the equivalent prisms, $S = P' + Q' = \sin^{-1} (\sin P \cos R) + \sin^{-1} (\sin Q \cos R')$.

Let us propose to ourselves a few practical problems as, given a prism of 8°

revolved upward through 10°, and a prism of 9° revolved downward 15°, then our formula becomes

$$S = \sin^{-1}(\sin 8^\circ \cos 10^\circ) + \sin^{-1}(\sin 9^\circ \cos -15^\circ)$$

where 15° has a minus sign before it, since we have arbitrarily assumed that angles of rotation made by revolving the prisms upward are considered positive and those downward negative.

$$\begin{aligned} \log \sin 8^\circ &= 9.14356 \\ \log \cos 10^\circ &= \underline{9.99335} \\ \log \sin P' &= 9.13691 \end{aligned}$$

where P' is defined by the equation $\sin P' = \sin 8^\circ \cos 10^\circ$ and $P' = \sin^{-1}(\sin 8^\circ \cos 10^\circ)$.

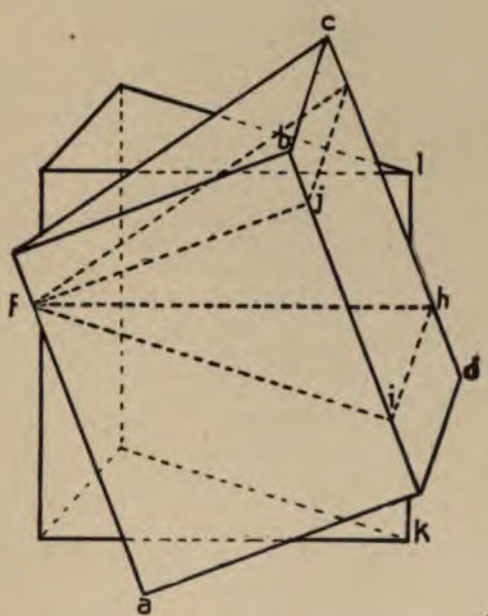

FIG. 199.—One prism revolving on another.

Looking in the table for an angle the logarithm of whose sin is 9.13691, we find $P' = 7^\circ\ 52'.66$.

For the last part of our equation

$$\begin{aligned} \log \sin 9^\circ &= 9.19433 \\ \log \cos 15^\circ &= \underline{9.98494} \\ \log \sin Q' &= 9.17927 \end{aligned}$$

where Q' is defined by the equation $\sin Q' = \sin 9^\circ \cos 15^\circ$ and $Q' = \sin^{-1}(\sin 9^\circ \cos 15^\circ)$.

Looking in the table for an angle the logarithm of whose sin is 9.17927, we find $Q' = 8^\circ\ 41'.45$, $S = P' + Q' = 7^\circ\ 52'.66 + 8^\circ\ 41'.45 = 16^\circ\ 34'.11$.

For another problem let us assume that one prism has an angle of 10° and is revolved upward through 5°, and that attached to it is another prism of 8° revolved upward through 120°, here $P = 10^\circ$, $R = 5^\circ$, $Q = 8^\circ$, $R' = 120^\circ$.

$$S = \sin^{-1}(\sin 10^\circ \cos 5^\circ) + \sin^{-1}(\sin 8^\circ \cos 120).$$

$$\begin{aligned}\log \sin 10^\circ &= 9.23967\\ \log \cos 5^\circ &= \underline{9.99834}\\ \log \sin P' &= 9.23801\end{aligned}$$

where P' is defined in a manner similar to that above, and equals $9^\circ\ 57'.69$. Regarding the second part of our equation, the log cos 120° is not given in the tables and we must find an equivalent expresssion.

$$\cos 120^\circ = \cos(180^\circ - 60^\circ) = -\cos 60^\circ$$

$$\sin^{-1}(\sin 8^\circ \cos 120^\circ) = \sin^{-1}\left(\left\{\sin 8^\circ\right\}\left\{-\cos 60^\circ\right\}\right) = \sin^{-1} - \left\{(\sin 8^\circ \cos 60^\circ\right\})$$

$$\begin{aligned}\log \sin 8^\circ &= 9.14356\\ \log \cos 60^\circ &= \underline{9.69897}\\ \log \sin Q' &= 8.84253\end{aligned}$$

where Q' is defined by the equation, $\sin Q' = \sin 8^\circ \cos 60^\circ$, whence $\sin - Q = -\sin 8^\circ \cos 60^\circ$ and $-Q = \sin^{-1}(-\sin 8^\circ \cos 60^\circ)$.

Looking up the angle the logarithm of whose sin is 8.84253 we find $Q' = 3^\circ\ 59'.42$, but the equivalent of the expression $\sin^{-1}(-\sin 8^\circ \cos 60^\circ)$ is $-Q'$ hence our angle is $-3^\circ\ 59'.42$. From above

$$\begin{aligned}S &= \sin^{-1}(\sin 10^\circ \cos 5^\circ) + \sin^{-1}(\sin 8^\circ \cos 120^\circ)\\ &= P' \qquad + \qquad (-Q')\\ &= 9^\circ\ 57'.69 - 3^\circ\ 59'.42 = 5^\circ\ 58'.27\end{aligned}$$

The truth of these formulas is apparent if we consider a few simple problems of which we know the answer. Suppose the two prisms are equal and we revolve one through 180°, keeping the other fixed, then the two prisms ought to neutralize each other. Let us see if they do. Here,

$$\begin{aligned}&P = Q,\ R' = 0,\ R = 180\\ &S = \sin^{-1}(\sin P \cos 180^\circ) + \sin^{-1}(\sin P \cos 0^\circ)\\ &\cos 180^\circ = -1,\ \cos 0^\circ = +1\\ &S = \sin^{-1}(-\sin P) + \sin^{-1}(\sin P)\end{aligned}$$

but $-\sin P = \sin - P$, hence $\sin^{-1}(-\sin P) = \sin^{-1}(\sin - P) = -P$, and $\sin^{-1}(\sin P) = +P$, hence

$$S = -P + P = 0$$

If one prism is held fixed as before and the other revolved through 90°, then we have the effect of one prism. Here,

$$S = \sin^{-1}(\sin P \cos 90^\circ) + \sin^{-1}(\sin P \cos 0^\circ)$$

but $\cos 90^\circ = 0$, and $\cos 0^\circ = 1$, hence

$$S = \sin^{-1}(0) + \sin^{-1}(\sin P) = 0 + P = P.$$

§ 5. **What is the Actual Deflection Produced by a Prism?**—In the right-angle triangle ABC, (Fig. 200) the distance AB being always 100 centimeters, the line BC represents the amount of deflection caused by a prism placed at the point A in the position of minimum deviation. Thus if a prism of 5 degrees were to cause a displacement of 4.5 centimeters along such a line, then the tangent of the angle between the normal and refracted rays would be found simply by dividing the length of the opposite side by the length of the adjacent side, that is $\frac{4.5}{100}$. In the table of natural tangents this corresponds to an angle of 2° 34′. Thus

TABLE OF NATURAL TANGENTS

Angle of the prism.	Linear deflection in centimeters.	Angle to which the linear deflection is tangent.	Same in decimals.
1	0.91	0° 31′.20	0.502°
2	1.82	1° 02′.42	1.040°
3	2.72	1° 33′.62	1.560°
4	3.63	2° 04′.92	2.084°
5	4.55	2° 36′.25	2.604°
6	5.46	3° 07′.65	3.013°
7	6.38	3° 39′.09	3.651°
8	7.30	4° 10′.66	4.178°
9	8.23	4° 42′.29	4.705°
10	9.16	5° 14′.07	5.235°
11	10.10	5° 45′.98	5.766°
12	11.04	6° 18′.02	6.300°
13	11.99	6° 50′.19	6.837°
14	12.95	7° 22′.58	7.376°
15	13.91	7° 55′.13	7.919°
16	14.88	8° 27′.86	8.464°
17	15.87	9° 00′.87	9.014°
18	16.86	9° 34′.11	9.569°
19	17.86	10° 07′.56	10.126°
20	18.87	10° 41′.32	10.688°

it is evidently easy to construct a table of these deflections. In this, the first column to the left gives the angles of the prism as measured by the goniometer or otherwise, the

second column shows the amount of linear deflection produced, and the third gives the tangents of the angles. Although such a table is simple enough, a search through the literature showed that it had been prepared only once. That was by Bisinger (B 778, p. 72). But unfortunately his figures are wrong. For on proving the angles with a table of natural tangents, it appears that he gives the *sine* of the angle, when he himself says it should be the tangent. Of course, these figures are subject to slight variations, due to the difference in the density of the glass, but simple as the table is, it is worth while to correct it and give it for the convenience of those who otherwise may look for it in vain. Moreover, such a table is frequently needed in the conversion of meter angles into degrees, and the reverse. Later we shall see the importance of this, when, in the pathological part of our study, we express degrees of muscle imbalance in terms as exact as possible.

FIG. 200.—Deflection caused by a prism.

§ 6. Prismatic Effect Produced by Decentering Lenses.—In clinical terms we say that a lens is decentered when its axis does not coincide with the optic axis of the eye before which it is placed. When that occurs a prismatic effect is produced, as can be easily seen by moving a convex or concave lens before the eye. The amount of prismatic effect produced by a given amount of decentering is evidently dependent upon two factors, the strength of the glass, and the distance which the optic axis and the axis of the lens are separated from each other. It is not difficult to obtain a formula which will express properly the relation of these two factors to each other. Opticians are accustomed to figure that a lens which is decentered one centimeter will produce as many prism-diopters as it has diopters of refraction. Thus, that if a lens of five diop-

ters is decentered one centimeter, it will produce a displacement of five prism-diopters; and when it is decentered two centimeters it will produce a displacement of ten prism-diopters, etc. The following is a table showing more exactly the number of millimeters which it is necessary to decenter a spherical lens in order to add a prism of from 1° to 5°.

+ or — glass of	Strength of Prism.				
	1	2	3	4	5
0.25					
0.50	18.5				
0.75	12.3				
1.00	9.2	18.5			
1.25	7.4	14.8	22.2		
1.50	6.2	12.3	18.5		
1.75	5.3	10.6	15.9	21.1	
2.00	4.6	9.2	13.9	18.5	
2.25	4.1	8.2	12.3	16.4	20.5
2.50	3.7	7.4	11.1	14.8	18.5
2.75	3.4	6.7	10.1	13.4	16.8
3.00	3.1	6.2	9.2	12.3	15.4
3.25	2.8	5.7	8.5	11.4	14.2
3.50	2.6	5.3	7.9	10.6	13.2
4.00	2.3	4.6	6.9	9.2	11.5
4.50	2.1	4.1	6.2	8.2	10.3
5.00	1.8	3.7	5.5	7.4	9.2
5.50	1.7	3.4	5.0	6.7	8.4
6.00	1.5	3.1	4.6	6.2	7.7

Evidently it is unnecessary to calculate the distances which the weaker glasses must be decentered to equal the weaker prisms, because we soon find that the amount of decentering is far greater than the entire width of an ordinary spectacle or eye-glass.

DIVISION II.

Convergence.

§ 1. **Convergence and Definition of the Meter Angle.**— Convergence consists in an angular motion of the visual axes toward each other. In the normal condition, both accommodation and torsion keep pace approximately with the degree of convergence, the amount being in proportion to the size of the angle which the visual axes make with each other. The earlier ophthalmologists were accustomed to estimate convergence in degrees of that angle, but after the metric system had been brought into ophthalmology at Nagel's suggestion (B 704) it occurred to him to express convergence also in terms of what he designated the " meter angle." This we understand as the amount of convergence required for the visual axes of a given individual to meet at a point situated one meter distant from the center of the line which connects the center of motion of the two eyes—that is, from the center of the base line. Thus (Fig. 201) if OO is the distance between the centers of motion of the two eyes and MR a perpendicular one meter long, erected at the middle of that line, then the angle QOR, or its equivalent ORM, is called one-meter angle. If the visual axes cross at a point twice as near to the eye—that is, at half a meter distant, then the angle of convergence is said to be two-meter angles, and so on. This method of expressing the amount of convergence in terms of a meter is not only ingenious but convenient, and its clinical advantage is well known.

§ 2. **Meter Angles Expressed in Degrees.**—The question is: Given the length of the base line and the angle of convergence expressed in meter angles, what is the size of that angle when expressed in degrees and minutes?

In order to find the angle of convergence in Fig. 201 let

OM = d, and the distance of the object = n; let C = the angle which each eye converges.

$$\text{Then } \sin C = \frac{d}{n}$$

For example, if the distance between the eyes in a given individual is 58 millimeters and the distance of the object (n) = ¼ meter, then the sine of the meter angle $= \frac{29 \text{ mm}}{250 \text{ mm}} =$ .11600, and we find from a table of natural sines that this decimal corresponds to the sine of an angle of 6°–40′.

Nowhere in the literature was there a table of the angles

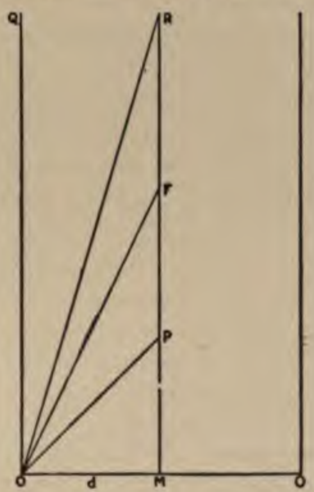

FIG. 201.—The meter angle.

at which eyes converge for all possible lengths of the line OO′. Nagel's calculations, which cover all variations in the base line from 55 to 75 millimeters, are based on a convergence of one-meter angle only, while those for degrees of convergence from one-meter angle up to twenty are only for a person with a base line of 64 millimeters. These two sets of calculations have been copied in Landolt, Norris and Oliver, and in other text-books. But they cover only a very limited range. It seemed worth while therefore to complete this table (B 810). The first column on the left gives the

METER ANGLES OF CONVERGENCE.

Distance between the eyes	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
55 mm.	1° 35'	3° 09	4° 44'	6° 19	7° 54'	9° 30	11° 06'	12° 43'	14° 20'	15° 58'	17° 36'	19° 16'	20° 57'	22° 39	24° 22'	26° 06
56 "	1 36	3 13	4 49	6 26	8 03	9 40	11 18	12 57	14 36	16 16	17 56	19 38	21 21	23 05	24 50	26 37
57 "	1 38	3 16	4 54	6 33	8 12	9 51	11 30	13 11	14 52	16 34	18 16	20 00	21 45	23 31	25 19	27 08
58 "	1 40	3 19	4 59	6 40	8 20	10 01	11 43	13 25	15 08	16 51	18 36	20 22	22 09	23 57	25 47	27 39
59 "	1 41	3 23	5 05	6 47	8 29	10 12	11 55	13 39	15 24	17 09	18 56	20 44	22 33	24 24	26 16	28 10
60 "	1 43	3 26	5 10	6 54	8 38	10 22	12 07	13 53	15 40	17 27	19 16	21 06	22 57	24 50	26 45	28 41
61 "	1 45	3 30	5 15	7 00	8 46	10 33	12 20	14 07	15 56	17 45	19 36	21 28	23 22	25 17	27 14	29 13
62 "	1 47	3 33	5 20	7 07	8 55	10 43	12 32	14 22	16 12	18 04	19 56	21 50	23 46	25 43	27 43	29 44
63 "	1 48	3 37	5 25	7 14	9 04	10 54	12 44	14 36	16 28	18 22	20 16	22 13	24 10	26 10	28 12	30 16
64 "	1 50	3 40	5 31	7 21	9 12	11 04	12 57	14 50	16 44	18 40	20 37	22 35	24 35	26 37	28 41	30 48
65 "	1 52	3 41	5 36	7 28	9 21	11 15	13 09	15 04	17 00	18 58	20 57	22 57	24 59	27 04	29 11	31 20
66 "	1 51	3 47	5 41	7 35	9 30	11 25	13 21	15 18	17 17	19 16	21 17	23 20	25 24	27 31	29 40	31 52
67 "	1 55	3 50	5 46	7 42	9 39	11 36	13 24	15 33	17 33	19 34	21 37	23 42	25 49	27 58	30 10	32 25
68 "	1 57	3 54	5 51	7 49	9 47	11 46	13 46	15 47	17 49	19 53	21 58	24 05	26 14	28 25	30 40	32 57
69 "	1 59	3 57	5 56	7 56	9 56	11 57	13 58	16 01	18 05	20 11	22 18	24 27	26 39	28 53	31 10	33 30
70 "	2 00	4 01	6 02	8 03	10 05	12 07	14 11	16 16	18 22	20 29	22 39	24 50	27 04	29 20	31 40	34 03
71 "	2 02	4 04	6 07	8 10	10 13	12 18	14 23	16 30	18 38	20 48	22 59	25 13	27 29	29 48	32 10	34 37
72 "	2 04	4 08	6 12	8 17	10 22	12 28	14 35	16 44	18 54	21 06	23 20	25 36	27 54	30 16	32 41	35 10
73 "	2 06	4 11	6 17	8 24	10 31	12 39	14 48	16 59	19 10	21 24	23 40	25 59	28 20	30 44	33 12	35 44
74 "	2 07	4 14	6 22	8 31	10 40	12 50	15 01	17 13	19 27	21 43	24 01	26 22	28 45	31 12	33 43	36 18
75 "	2 09	4 18	6 28	8 38	10 48	13 00	15 13	17 27	19 43	22 01	24 22	26 45	29 11	34 14	31 40	36 52

length of the base line in millimeters, while the upper horizontal line shows the number of meter angles of convergence. Knowing these, the corresponding angle of convergence in degrees and minutes can be seen at a glance.

§ 3. **Degrees of Convergence Expressed in Meter Angles.**—This question is: Given the length of the base line and the angle of convergence expressed in degrees, what is the size of that angle when expressed in meter angles?

This deserves a place in our study not only because it is in part a restatement of the problem which has just been considered, but because of the very practical use which can be made of the data thus obtained. The calculation is easy, depending simply on a change of the formula already employed.

The meter angle $= \frac{1}{n}$

Again if C = angle which each eye converges, then

$$\sin C = \frac{d}{n} \text{ or } \frac{1}{n} = \frac{\sin C}{d}$$

In this we have given, d (one half the base line) and sin C. This gives $\frac{1}{n}$ in meter angles when d is expressed in meters.

For example, in a person with a base line of 62 millimeters and a convergence of 6°,

$$\frac{\sin 6^\circ}{d} = \frac{0.10453}{0.031} = 3.37 \text{ meter angles.}$$

The results are found in the accompanying table. The line above represents the length of the base line expressed in millimeters extending from fifty-five to sixty-six. The first vertical column on the left gives the size of the angle of convergence of one eye—that is, the angle which one visual axis makes with the perpendicular erected at the center of the base line M. It is the angle ORM or OFM, etc. This angle is calculated from one degree to twenty for each eye, or from two to forty degrees, of course, for both. The figure then in each of the vertical columns represents the size of this angle in terms of the meter angle.

Degrees	Base Line in Millimeters											
	55	56	57	58	59	60	61	62	63	64	65	66
1	0.63	0.62	0.61	0.60	0.59	0.58	0.57	0.56	0.55	0.54	0.54	0.53
2	1.27	1.25	1.22	1.20	1.18	1.16	1.14	1.12	1.11	1.09	1.07	1.06
3	1.90	1.87	1.84	1.80	1.77	1.74	1.72	1.69	1.66	1.64	1.61	1.59
4	2.54	2.49	2.45	2.40	2.36	2.32	2.29	2.25	2.21	2.18	2.15	2.11
5	3.17	3.11	3.06	3.00	2.95	2.90	2.86	2.81	2.77	2.72	2.68	2.64
6	3.80	3.73	3.67	3.60	3.54	3.48	3.43	3.37	3.32	3.27	3.22	3.17
7	4.43	4.35	4.28	4.20	4.13	4.06	4.00	3.93	3.87	3.81	3.75	3.69
8	5.06	4.97	4.88	4.80	4.72	4.64	4.56	4.49	4.42	4.35	4.28	4.22
9	5.69	5.59	5.49	5.39	5.30	5.21	5.13	5.05	4.97	4.89	4.81	4.74
10	6.31	6.20	6.09	5.99	5.89	5.79	5.69	5.60	5.51	5.43	5.34	5.26
11	6.94	6.81	6.70	6.58	6.47	6.36	6.26	6.16	6.06	5.96	5.87	5.78
12	7.56	7.43	7.30	7.17	7.05	6.93	6.82	6.71	6.60	6.50	6.40	6.30
13	8.18	8.03	7.89	7.56	7.63	7.50	7.38	7.26	7.14	7.03	6.92	6.82
14	8.80	8.64	8.49	8.34	8.20	8.06	7.93	7.80	7.68	7.56	7.44	7.33
15	9.41	9.24	9.08	8.92	8.77	8.63	8.49	8.35	8.22	8.09	7.96	7.84
16	10.02	9.84	9.67	9.40	9.34	9.19	9.04	8.89	8.75	8.61	8.48	8.35
17	0.63	10.44	10.26	10.08	9.91	9.74	9.58	9.43	9.28	9.14	9.00	8.86
18	11.24	11.04	10.84	10.66	10.48	10.30	10.13	9.97	9.81	9.66	9.51	9.36
19	11.84	11.63	11.42	11.23	11.04	10.85	10.67	10.50	10.33	10.17	10.02	9.86
20	12.44	12.22	12.00	11.80	11.60	11.40	11.22	11.03	10.86	10.69	10.52	10.37

It may naturally be asked why we devote so much time to the calculation of this table, or of what value it is when finished? In the first place, it seems always worth while thus to complete by mathematical data the physiological basis on which our knowledge of the muscles must rest. But this table has another and more immediate value. It helps us to translate into modern terms the data which were found by the earlier students, especially those who made their calculations before Nagel introduced the meter angle into ophthalmology. The result is that the measurements of Helmholtz (B 584), Donders (B 590), Hering (B 586), and Landolt (B 592) are practically lost to us because we cannot express them in terms of a meter angle without a tedious calculation each time. But this table permits that transposition to be made at a glance. Moreover, we shall see that these earlier measurements of convergence, in their relation to accommodation or to torsion—data which have lain forgotten in *Graefe's Archives* for a third of a century or more—prove to be of decided clinical value in the light of modern

methods of investigation. Finally, this table enables us to express also in meter angles the result of our examinations with prisms as to the static and dynamic conditions of convergence. Thus an esophoria of five degrees means that the visual axis of the eye tested tends to make a certain definite angle with a perpendicular to the center of the base line in the horizontal plane, and as we can easily find the base line by methods already given, we know at once the fraction of a meter angle which that esophoria would represent if it were a corresponding esotropia.

As we are able to represent accommodation by a line divided into equal parts, each one of which corresponds to one diopter, so can we also represent convergence by a line divided into equal parts, each one of which corresponds to one meter angle of convergence. In other words, accommodation is made to accord with convergence, and that, in turn, in a certain way with forms of heterotropia. Later we shall find that in a similar manner torsion may be expressed diagrammatically. This gives us, as we shall see, a manner of representing the relation of accommodation, of convergence and of torsion to each other. In other words, these tables assist us in bringing our scattered data into relation with each other.

§ 4. **What is the Relative or Fusion Power ?**—In a previous chapter, when studying the motions of one eye alone, we found that the adductor group could exert a sufficient force to lift a certain weight and the energy expended in doing this was called the *lifting* power or *absolute* power of adduction.

But the power of the adductor muscles can be exerted in another way—that is, by placing prisms base out before one eye or both ; then, in the effort to avoid double vision, one eye or both turn in. As this effort is one exerted *in relation* to the opposing groups of muscles, we can properly call it the *relative* power of adduction. Its object is to fuse the retinal images. While this *relative* or *fusion* power of adduction is to be clearly distinguished from the absolute or lifting power of that group, as the latter has thus far been studied so little, we will understand

in the future that the relative or fusion power is referred to, unless the contrary is stated. It depends upon two factors, the actual strength of the recti muscles and the so-called instinctive desire of fusion. Both of these vary in different individuals. Although we are confining our attention now to the power of adduction in overcoming prisms, if we remember that the same principle applies to abduction, superduction, subduction, etc., much repetition can be avoided.

How is this Relative or Fusion Power Measured?—Although this is a subject already perfectly familiar to most readers, it is worth while to review it here in order, if possible, to clear up, from the physiological standpoint, the confusion which exists clinically. To begin with an elementary statement: If the parallel visual axes are directed toward a distant object—a point of light, for example—and a prism is held before the right eye with the base out, then, as the ray from the light passes through the prism and is deflected towards its base, the image of the light falls, not on the fovea of the right eye, but on its outer side, and crossed diplopia results. Whenever such diplopia occurs, there is an instinctive desire to overcome it, and immediately the eye tends to turn inward to meet the ray thus deflected outward. If the prism is a weak one, the adductor muscles turn the eye far enough inward to overcome the diplopia. With a stronger prism, the eye turns in still more, and again more, but the limit of the ability of the abducting muscles of each eye to turn the globe toward the median line is finally reached, and the strongest prism which the abductor muscles can thus "overcome" is said to represent the power of adduction of that pair of eyes. Half the strength of the prism would be the adductive power of one eye. In a similar way we measure the power of abduction by turning the prism with the apex outward, or of superduction and subduction by turning the apex down and up. These facts are part of the basal knowledge of every ophthalmologist. Unfortunately, however, we are very far from agreeing on the interpretation of the data obtained by this very simple procedure.

We have most confused statements of how the power of adduction should be measured, what its amount is in a normal condition, what its value is clinically, and, indeed, whether such examinations have any value at all. Yet these are all important questions, and it is necessary to establish them clearly on a physiological basis or we shall continue to flounder in a confusion of methods and theories. If we turn first to our methods of making the examinations, that will perhaps indicate in what one part of the trouble lies. Let us begin by placing a prism of five degrees, base out, before the right eye. Suppose the eye overcomes this prism and others of gradually increasing strength, as they are selected *from the test case*, until we find at last that one of nine degrees represents the total adductive power. Or we may begin with prisms of twelve or fourteen degrees taken again *from the test case*, and, decreasing from that point, find again that one of nine degrees is the strongest which the adductor muscles can overcome. If, however, we vary that method of testing by *gradually* increasing the strength of the prism *without allowing the eye an interval in which to rest*, the result is usually different. If we use the prisms in series of Noyes or others like them, the amount of adduction can be brought to ten or twelve, and if we use Risley's prisms or some of the other rotating prisms in which the increment is still more *gradual and without interruption*, the adductive power in the same individual at the same sitting can be brought perhaps to fifteen or eighteen, or in occasional instances to a much greater number of degrees proportionately. Evidently, then, we have different results dependent upon different methods of testing. At present we confuse these. They are certainly distinct physiologically, and should be distinguished clinically. For convenience, we could classify them as follows:

First. *The minimum relative or fusion power* of a group of muscles is that which we obtain by placing different prisms before the eye, leaving a considerable *interval between the tests*, or it is that which is found when we pass *from a prism strong enough to produce diplopia to one which can be overcome.*

Second. *The maximum relative or fusion power* of a group of muscles is that which we obtain when we pass *by gradual increment from a prism which is not strong enough to produce diplopia to one which cannot be overcome.*

Third, as confusion and misunderstandings often occur in recording the results of any such tests, we should specify what is meant by the figure used. If it is the strength of one prism or, what is the same thing, if it is the sum of the strength of the prisms held before each eye, then we may properly call that the *total* minimum (or maximum) power of adduction or abduction, etc. If, however, the figure used expresses only half of the sum of the strength of the prisms held before each eye, then that fact should be clearly stated.

The difference between the minimum and maximum power of any group of muscles, especially in adduction and abduction, can ordinarily be found at once on making this simple test. In some persons it is true that there is practically no difference, while in others there is a wide range of from six, eight, to ten degrees or more.

The importance of this distinction is great. Until it is made, and until we agree upon some uniform method for this portion of our clinical work, we do not understand each other.

§ 5. **What is the Minimum Fusion Power of the Various Groups of Muscles?**—In this division of the fourth group of movements, we are dealing in a strict sense only with convergence. But divergence is really, as Landolt has called it, a *minus convergence.* Therefore we can with advantage glance at divergence also in this connection. Or, if we include at this point efforts to fuse images in the vertical meridian, it will be unnecessary to refer to them again.

Different methods have been employed for testing normal and abnormal eyes and naturally the results appear contradictory. An idea of this confusion can be obtained by arranging the observations of a few American writers in tabular form, as on the next page. This shows the amount

of adduction, abduction, etc., when the test object is at a distance of six meters.

Name of Observer	Year	Bibliography	Condition of eyes examined	How many	Adduction	Abduction	Superduction	Subduction
Noyes	1890	705 p.113	Not stated	?	36 to 45	6 to 8	?	?
Stevens	1897	725	" "	?	50.?	8.	2.	2
Risley	1894	537	Normal	25	25.4	8.1	?	?
Bannister	1897	726	"	100	14.4	8.	2.	

As it seemed probable that the varying results which were obtained, at least for adduction, were due partly to the fact that some observers included examinations of abnormal eyes, and as nearly all employed different tests, it appeared to me worth while to go over this ground again. Accordingly an examination as to this point was made of 56 soldiers at Fort Porter, of 31 Harvard students, and 16 pairs of non-asthenopic eyes among my colleagues and other friends, or a total of 103 individuals. With all of these, the prisms were used, as already described, so as to obtain only the minimum fusion power. The results were as follows: Adduction 9.7; abduction 6.8; superduction 2.3; subduction 2.

It is probable that these figures will need some revision not only because the number of persons was small, but apparently the results are influenced by the age of the individuals and other factors. The power of fusion which comes with convergence at the near point will be considered in Section 8. It is interesting to notice that although there are considerable differences of opinion as to the fusion power for adduction when the test object is at a distance of six meters, on the other hand the observers agree quite well as to the power of abduction, superduction, and subduction.

Reference will be made to this point also in connection with pathological aspects of the question.

§ 6. **What is the Amount of the Maximum Fusion Power of the Various Groups of Muscles?**—It is impossible to state this even approximately, for the reason that when we use prisms of gradually increasing strength, so as to "exercise" the muscles, the result depends principally on the methods employed and the persistence shown by the individual. Tscherning (B 230) has called attention to the readiness with which eyes adjust themselves to unusual positions in physiological experiments, and has shown that it is easy to increase the power of adduction within a few days simply by systematic practice with proper prisms. No discomfort is experienced after the experiment, and for all practical purposes the eyes are the same in spite of the increased maximum power.

The figures given by Stevens (B 725), of adduction 50°, as well as the context of his statement, indicate that he referred to the maximum power.

Data on this point are also furnished by those who attempt to "develop" what they call "latent esophoria" or other forms of heterophoria. This will be considered in the study of the clinical aspect of the subject. Suffice it to explain here that this condition has been compared to that of the ciliary muscle which is revealed by the use of atropin. In the latter case we have a certain amount of hypermetropia which is manifest, and the atropin reveals a certain additional amount which is latent. In a similar way, it is said that before prisms are used a certain amount of muscular power is "manifest," but that with the prisms, a much larger amount becomes possible, and hence the difference is "latent." In proof of this, cases are cited to show that because the asthenopic symptoms did disappear under this treatment, therefore such latent heterophoria must have existed, and, on the other hand, when relief was not obtained, then this latent heterophoria did not exist, even though the muscles were developed to a very marked degree. Without commenting otherwise on this proposition, it may be observed that this "developing" of the latent heterophoria is something

which may be done by almost any one who has normal eyes, if he will take the trouble to use prisms of increasing strength regularly and patiently, even for a comparatively short time. This experiment I have tried at different times, and the fact is easily demonstrated. Such experiments on normal or abnormal eyes thus show how readily the muscular power can be increased, and indeed no limit within the bounds of credulity seems to have been placed on the power of fusion. In a word, the maximum fusion power is of some interest for the sake of comparison, but certainly is not of as much importance in itself as many writers on the subject would lead us to believe.

§ 7. **Balance of Power in Groups of Muscles.**—It should not be inferred that relative weakness in a certain group of muscles as measured in terms of prisms, is an indication of inability of that group of muscles to do its work in a physiological manner. In different individuals whose eyes are practically normal, the minimum power of adduction, for example, may be quite small, occasionally only half of the average, but in these individuals we find ordinarily that the minimum power of the opposing group is also less than normal, and often in a corresponding degree.

On the other hand, there are individuals who have a minimum power of adduction largely in excess of the average, and in these we are apt to find a correspondingly large amount of abductive power. In other words, it is certain that in the normal condition we may have decided variations in the relative strength of different individuals, but that the balance between the opposing groups of muscles remains in a general way about the same. A pair of scales will balance whether there is a weight of ten grams or a hundred grams on either side.

§ 8. **Test of Muscle Balance with Convergence.**—We have seen that when the visual axes are parallel, and the eyes are in the apparent static condition (as ordinarily tested), heterophoria is about as frequent as orthophoria. That is not the case when accommodation and convergence are brought into action. This is an important fact. In order to appreciate its significance, let us understand (*a*) how we are to make our

measurement, (*b*) how we are to designate the results obtained, and (*c*) what these results really mean.

(*a*) In order to determine whether this "balance" exists at the working distance, the ordinary method is to use a vertical line with a dot in the center, such as was suggested first by Graefe. For this purpose a short thick line, with a small dot at its center is often employed (Fig. 202). But this is confusing, and unsatisfactory replies result. It is therefore better to use a long fine line with a large distinct dot (Fig. 203), and if this is drawn on one edge of the paper on which the small test letters are printed, it is always at hand for the examiner. The usual test with this, as is well known, is to place before one eye of the subject a prism with the base down, and ascertain whether the vertical line and dot, when viewed at the near point, appears directly above the dot seen with the uncovered eye, or whether the upper dot is above and to the right, or above and to the left of the other dot.

FIG. 202. Line and dot of Graefe. As it should *not* be drawn.

(*b*) If the line is a long one and the prism is not too strong, then, when the individual sees only one long vertical line with two dots in its course, we say that "muscle balance" exists for that point, whether it be three, four, or five meter angles of convergence. This condition is often described as "orthophoria at the near point." That term, however, is both contradictory and indefinite. If orthophoria is a "tending of the visual lines in parallelism," evidently that can not occur with convergence. Moreover, the term "near point" alone is indefinite, and, unless otherwise specified, we should understand by it three meter angles of convergence. Of course when the measurement is made in this way, if the two dots are not in the same vertical line they can be made to appear so by placing a second prism at right-

FIG. 203. Line and dot of Graefe. As it *should be* drawn.

angles to the first, as when correcting a heterophoria. The position and strength of this second prism then shows the kind and degree of heterophoria which exists with convergence at a certain number of meter angles, whatever that may be.

(*c*) Finally, as to results of these tests in normal eyes. An examination of the non-asthenopic eyes of the 103 persons just referred to showed that perfect muscle balance at the near point of three meter angles was present in a fraction over 93 per cent. This is a very much larger percentage than that in which we find orthophoria at the far point. More-

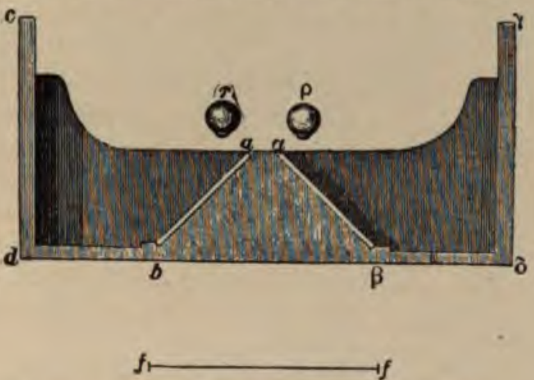

FIG. 204.—The reflecting stereoscope of Wheatstone.

over, the greater the degree of accommodation and convergence, up to the limit of a comfortable working distance, the more constantly do we find perfect muscle balance.

§ 9. **Stereoscopes.**—In the clinical portions of this study we shall find that the stereoscope is of decided assistance in treating certain forms of muscular difficulties; therefore, aside from its intrinsic interest in connection with convergence, it is advisable at this point to understand exactly what is meant by this instrument. For we must distinguish two varieties, the reflecting and the refracting stereoscope. The one invented by Wheatstone, in 1848, was the reflecting stereoscope (Fig. 204). In this the picture seen by the right eye, for example, is reflected into a mirror (ab) which is placed at an angle of forty-five degrees to the axis of vision. If this

mirror is turned laterally, it is evident that the eye of the observer must make a corresponding amount of convergence or divergence in order to be in line with the reflected ray. In the original stereoscope of Wheatstone, the picture and the mirror were stationary. In later modifications, for clinical purposes the two mirrors are attached by a hinge, and thus the angle at which they stand can be altered as desired.

In 1849 Brewster constructed the familiar refracting stereoscope (Fig. 205). In this, each picture is seen with the corresponding eye through a convex lens so decentered as to act as a strong prism. This causes not only a slight magnification of the pictures, but also makes them overlap slightly, and in doing so produces a single retinal image.

FIG. 205.—The refracting stereoscope of Brewster.

The clinical value of the refracting stereoscope is indicated by the number of modifications which it has undergone. Among those most in use are the stereoscopes of Bull, Richard Derby (Fig. 206), and others with similar adaptations. As these all depend on the same physiological principle, they need only be mentioned here. Their use will be referred to under the treatment of certain forms of heterophoria and heterotropia.

Most of the refracting stereoscopes are made so that the object is viewed only with considerable convergence, but long ago Noyes extended the long arm of the instrument, which carries the card a distance of three-fourths of a meter or more. With this simple modification it is possible to push the picture as far away as it is possible to see the details with exactness.[1]

The stereoscope cards already in use are so varied that it would seem superfluous to call attention to any one of them,

[1] Pictures especially adapted for ophthalmologists are published by C. Eckenrath, Berlin, and by others in this country.

were it not that I have found a simple arrangement to serve an excellent purpose, not only for physiological experiments, but for clinical purposes. This card is seen in Fig. 207, its advantage being largely in its simplicity. Before one eye there is drawn a horizontal line with a circle at its center, the distance from the center of the circle being marked off in millimeters from zero to forty. Before the other eye a

FIG. 206.—Derby's modification of the Brewster stereoscope.

vertical line is drawn. At its center there is a circle of the same size as the circle which is in the center of the horizontal line, and from the center of this circle in the vertical line twenty millimeters are marked off in each direction. The method of using such an arrangement suggests itself at a glance. When the stereoscope is placed in front of the observer, if he has good binocular vision it is easy for him, by adjusting the distance, to make the two circles overlap. If

he then approaches the card perhaps only a short distance, the circles separate, or, if the tendency to fusion is great, the card can be brought comparatively close to the eyes before the circles are separated. If the bar on which the rack for the card slides is marked off in centimeters, it is evidently easy to note the distance from the eyes at which the circles

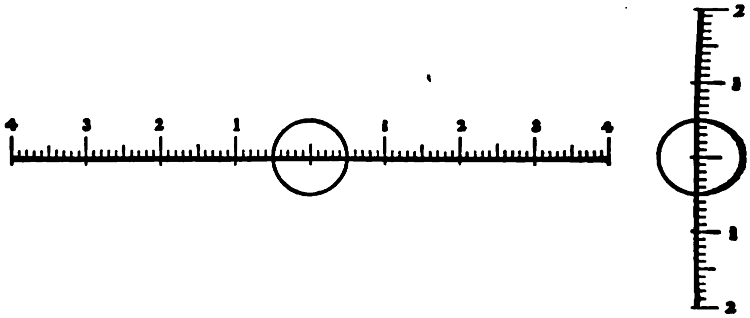

FIG. 207.—Stereoscopic picture adapted for lateral or vertical deviations.

begin to slip away from each other. By keeping a record of this distance and of the number of millimeters, right or left, up or down, which the two circles separate, or tend to separate from the other, we have a method of measuring the behavior of the ocular muscles under the same conditions at different times. Even the patient himself can thus observe what changes, if any, take place in his condition.

DIVISION III.

Relation of Accommodation to Convergence. Relative Accommodation.

§ 1. **Definition.**—The amount of accommodation which it is possible for an individual to exert or relax with relation to a given degree of convergence is called the *relative accommodation.*

In Figure 208 let us suppose the eyes to be accommodated and also converged to the point p. Then if concave glasses of gradually increasing strength are placed before the eyes, the person, while retaining the same degree of convergence, will be able to increase his accommodation up to a certain limit. This degree would be represented by the strongest concave glasses which he can overcome, and is equivalent to accommodation to a point nearer than that to which the eyes were converged, for example, to $p_{\prime\prime}$. The distance $pp_{\prime\prime}$ will then be the positive part of the relative accommodation.

FIG. 208.—Illustration of relative accommodation.

In like manner, if the person continues to converge to the point p, and convex glasses of gradually increasing strength are placed in succession before his eyes, he will be able to relax his accommodation up to a certain limit—for example, to $p_{\prime}$. The distance $pp_{\prime}$ will then be the negative part of the relative accommodation. Evidently, the total range of relative accommodation is equal to the sum of the negative and positive portions, or to the distance $p_{\prime}p_{\prime\prime}$.

§ 2. **Illustration of the Ranges of Accommodation for Varying Degrees of Convergence.**—A clearer idea of

the relative accommodation can be obtained if we represent graphically, even though approximately, the ranges which are found with varying degrees of convergence.

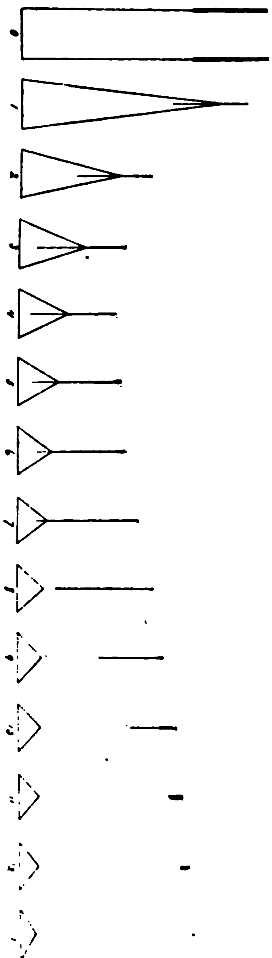

FIG. 209.—Diagram showing the range of accommodation with varying degrees of convergence. The amount of accommodation which is possible with each meter angle of convergence is shown by the vertical line.

For this purpose, let us suppose that we are testing the eyes of a young emmetrope, and that the following figures represent the ranges of accommodation which have been found by placing in succession, first concave and then convex glasses before the eyes.

Thus, in o of Figure 209, we see what occurs when this individual looks at test letters six meters distant. Since the visual axes are then parallel we cannot speak of accommodation in relation to convergence. But let us place concave glasses of −3 or −3.25 before the eyes of our emmetrope. He may not be able to read the letters at first, but after a few seconds and after an effort, of which he is usually conscious, he can see the letters. Evidently his crystalline lenses have become sufficiently convex to overcome the concave glasses in front of the eyes. That is, he has exerted 3 or 3.25 diopters of positive relative accommodation. If we attempt to represent this in a diagram, we must draw two parallel lines corresponding to the positions of the visual axes, and indicate on each line a point to which each eye is then accommodated. As for the negative portion of his relative accommodation, there is none to repre[illegible] For if convex glasses

are placed before the eyes of an emmetrope he has no accommodation to relax, and the image falling in front of the retina, the print becomes blurred. In other words, when an emmetrope looks with parallel visual axes, it is evidently possible to exert only the positive part of the relative accommodation.

Let us consider next the amount of relative accommodation which is possible with a slight convergence,—for instance, with suitable test types placed one meter distant. If we place a —2.5 or —3. before each eye he will ordinarily, after a few seconds, see the print distinctly. In other words, the positive portion of the relative accommodation is 2.5 or 3 diopters as the case may be. Or again, by placing a plus 0.5 or plus 0.75 before each eye he will, in a similar way, relax the accommodation to that degree—that is, the negative portion of the relative accommodation is 0.5 or 0.75. It is possible to represent approximately this amount of positive and of negative accommodation exerted with relation to that degree of convergence. Thus in figure 209, if the vertical line representing the relative accommodation be drawn to a scale, the total relative range for one meter angle is shown as in that part (1) of the diagram. With convergence to one-third of a meter, there is a little less of the positive portion and more of the negative, and this can be represented in a similar manner. With convergence to one-fourth, one-fifth, one-sixth, and one-seventh we notice in succession that the positive portion of the relative accommodation constantly decreases, while the negative portion constantly increases. This increase or decrease is not always regular, but there is always a tendency to that regularity. With convergence at one-eighth of a meter the emmetrope can not overcome any concave glass at all; in other words, there is no positive portion, but it requires all the effort which the ciliary muscles can make to accommodate enough to see the test object. But the accommodation can be relaxed to a degree which is represented by glasses of plus 5. diopters. Suppose the convergence is increased still further, to a point one-ninth of a meter in front of the eyes. Our emmetrope may converge to that point, but it is impos-

sible for him to accommodate to any object which is so near. Hence convex glasses must be used. Let us suppose plus 1.75 to be sufficient. With their aid, the image can again be brought upon the retina, and the weakest convex glasses which will enable him to see distinctly with that degree of convergence represent, of course, the nearest point of relative accommodation. Now if slightly stronger convex glasses are placed in front of the eyes, the individual simply relaxes his effort at accommodation in proportion. If other convex glasses, a little stronger, are placed before the eyes, he relaxes his accommodation more, and still a little more, all the while maintaining that same degree of convergence at one-ninth of a meter. If we continue placing in turn stronger convex glasses before the eyes, we find a point where our emmetrope can no longer relax his accommodation, and the glasses then used — for example, plus 6.25 — represent the farthest limit of the negative portion of the relative accommodation. Thus, with that degree of convergence, although the relative accommodation is all negative, there still exists a considerable range, represented in this case by the difference between plus 1.75 and plus 6.25. Strictly speaking, allowance should also be made for the distance of the glasses from the eyes, but this will be considered later. Suppose the convergence to be increased still farther—for example, to a point at one-tenth of a meter. Here again the accommodation can not be exerted to a point so very near, and the test letters suitable for that distance become even more indistinct than in the last instance. Moreover, greater assistance would be needed for the accommodation in order to bring the image on the retina. That is, instead of using a plus 1.75 before each eye a plus 4 or plus 4.5 would be required. Thus again, the weakest glasses necessary to supplement the crystalline lens would represent approximately the nearest point of the negative portion of the relative accommodation, while the strongest glasses—plus 7, for example—which give distinct vision would represent the greatest amount of relaxation. In other words, with the visual axes crossing at one-tenth of a meter, the relative range of accommodation again would be all negative and the range would be a little shorter than in the last

instance. With convergence to one-eleventh of a meter, the weakest convex glass necessary being 5.5, for example, and the strongest one possible being only 7.25, the difference between those two is less—that is, the range of accommodation is shorter. With convergence of one-twelfth of a meter, we would find the range still all negative and still shorter. At one-thirteenth of a meter we find that glasses as strong as plus 8 diopters are necessary to enable our emmetrope to see the proper line of letters at that distance. But we also find by trying other glasses that 8 plus is the strongest glass with which he can see—that is, he cannot relax the accommodation any farther. In other words, there is no range of negative relative accommodation with that degree of convergence, and consequently the range must be represented graphically not by a line but by a single point.

§ 3. **Desiderata for the Accurate Measurement of Relative Accommodation.**—The foregoing gives only an idea of what relative accommodation is, and how it can thus, in a simple way, be represented graphically in a given case. It is essential, however, that we learn how these measurements can be made accurately, not only because of what they teach the physiologist, but because of the decidedly important data which they often furnish to the clinician. For this purpose it is necessary to have certain conveniences and appliances, and it is desirable to become acquainted with these before attempting to make an examination even of a pair of normal eyes. These desiderata are:

(*A*) A visuometer with which to measure the interocular base line. This has already been described.

(*B*) A table to show the actual size of the meter angle with various degrees of convergence. This has also been given.

(*C*) An optometer (as seen in Fig. 210) or instrument for measuring relative accommodation and convergence. In another section an account will be given of other appliances which have been used by different observers for making these measurements. At present it is best to describe the latest model of the instrument used in these tests, with

the secondary appliances for this purpose, because it is the simplest and seems to be the most practical form.

A square brass rod, A A′, about 105 centimeters long, forms the stem of a "T" of which the cross-bar is another piece eight or ten centimeters long. The longer bar is supported at either end on a foot-piece, F and F′. The upright is so arranged that the height of the bar from the table can be varied some twenty or thirty centimeters. On either side of the short bar there is a disc or "carrier" of brass, D D, fifty millimeters wide and three or four millimeters thick, and

FIG. 210.—Optometer of the author.

each disc has near its center a slot in the form of an arc, graduated in degrees, C and C′. The center of this arc is exactly thirty millimeters beyond the end of the long bar. The zero point on the disc marks the position of an imaginary line parallel with the long arm of the T—that is, the position when the parallel visual axes are directed at an object in the horizontal plane. The degrees on the arcs measure therefore any convergence of the axes. Each slot is provided with a small nut, N and N′, accurately fitted and carrying an index line which marks its place with reference to the degree on the arc of the carrier. Each nut is also

provided with a short vertical bar supporting an arc in which a lens can be placed. The nut can be tightened or loosened by means of a thumb screw, whenever it is desired to change the angle at which the spherical glass is set with reference to the axes of the eyes of the observer. The distance between the two discs or carriers can be adapted to any pair of eyes, by means of a screw of double rotation, S S′, which brings them together or separates them as desired. This distance between the center of a given pair of eyes is recorded on an index which passes along a linear slot in the carrier and over a millimeter scale.

The long bar of the T is graduated in meter angles and carries a four-sided revolving frame (O) which can be slid back and forth. On each one of the four sides a small card of test objects is placed. The plane of the side which is turned toward the observer marks the distance in meter angles from the interocular base line of the eyes under observation. That distance can be easily made to correspond with one, two, three, and four or more meter angles. The use of this whole arrangement for measuring relative accommodation will be shown later.

Next let us consider more exactly the test types used with this instrument.

In former measurements made of relative accommodation, one of the difficulties encountered was to obtain test objects of the proper size in proportion to the distance at which they were viewed. The nearest approach to accuracy heretofore was obtained probably by Bisinger (B778), who made use of the minute dots advised by Bourchard. A few trials with these showed their imperfections. They are not sufficiently numerous or varied, and are therefore easily learned by the patient, and even the smallest are too large when viewed through the strong convex glasses used at the higher meter angles. Moreover, when these are magnified their edges appear blurred.

Fortunately, however, it is possible by the aid of photography to overcome these difficulties to a considerable degree. In any set of types properly constructed on the basis of the angle of minimum vision, we know that each element of the letter subtends an angle of fifty-five seconds. If

the letter to be seen by the normal eye at 100 meters measures 133 millimeters in both heighth and breadth, then the one intended for one meter would be one one-hundredth of that size. For our purpose, therefore, it is necessary first to obtain a series of types so constructed as to be visible at the following distances in meters: 100–50–33–25–20–16.6—14.2—12.5—11.1–10–9.0—8. 3—7.6—7.1—6.6—6.2—5.8—5.5—5.2—5.

When these are reduced on the glass plate of a camera to one one-hundredth of their original size, they are adapted for testing the vision at each meter angle respectively, from one to twenty. Fig. 211.

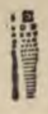

FIG. 211.—Series of letters for testing relative accommodation. Those actually used are photographed and are therefore much more distinct.

Theoretically this is simple enough, but there are practical difficulties not only in having such a series properly made, but especially in obtaining a clear picture of proper size on a pure white background.

Nothing concerning this could be found in the literature, and after having several sets photographed, I learned that Javal had devoted considerable time and care to preparing a similar series of microscopic letters. With the suggestions obtained from him, a series was secured which is perhaps as accurate as can be produced by our present methods. But with these tests, as with all others, difficulties are presented when glasses are placed at a short distance before the eye. Particles of dust or moisture on the lens, or slight decentering, easily blur the vision. Also when these tests are made on persons whose vision is not perfect or cannot be brought near to the standard of perfection by suitable glasses, a corresponding allowance must be made in the results obtained. Fortunately, however, these errors are usually not great, and by making corrections of the ametropia when necessary, the types described serve all practical purposes very well. They are mounted on one side of the small square frame which slides along the long bar. One or two series of such letters can be placed on other faces of the same square frame if greater exactness is desired.

(D) Another desideratum for the measurement of relative accommodation is a proper blank on which the data can be conveniently recorded. Such a blank should indicate by proper headings the date, case number, name, residence, and age of the person, with the length of the interocular base line.

The first column shows the distance in meter angles of the object from the individual when a given test is made.

The second gives the amount of accommodation which the individual ordinarily does exert with a given degree of convergence, this being dependent on the kind and degree of his ametropia, if any exists.

In the third column is entered the strongest concave glasses which he can overcome at each meter angle of convergence.

In the fourth is recorded the actual strength of the dioptric system with these glasses, after correction has been made for their distance from the eye, or in other words what is really the positive part of the relative accommodation.

The fifth column shows the strongest convex glasses which can be overcome, or when all of the accommodation is negative, the strongest and also the weakest glasses which the individual can overcome at each meter angle of convergence.

In the sixth is entered the actual strength of these glasses, or of the two pairs of convex glasses just mentioned, after correction has been made for their distance from the eyes, or in other words, what is the actual negative part of the relative accommodation.

Finally, in the last column the total range of the relative accommodation is entered. This of course is the sum of the positive and the negative amounts, or when all the relative accommodation is negative, the total range is then shown by the difference between the strongest and the weakest convex glasses, they being corrected for the distance from the eyes.

One of the blanks with the data inserted is shown on page 319.

§ 4. **Details of the Method of Measuring Relative Accommodation with the Optometer.**—An accurate measurement of relative accommodation with all possible degrees

of convergence is, without question, rather a tedious procedure demanding no small amount of exactness and patience on the part of the examiner and of the one examined. In order however to understand the process and the important relation of accommodation to convergence from the clinical standpoint, it is necessary to trace our way, for once at least, through the details of the measurement of a pair of normal eyes. Fortunately we shall find later, when we come to consider the clinical value of these measurements, that the tests which are most important can be made easily and quite quickly. It is essential for such an observation that the person examined should have an average degree of intelligence, and eyes of about the same amount of vision, so that the tendency to fusion of the images is always maintained.

As a preliminary step, the interocular base line should be measured by means of the visuometer (page 215). Let us suppose that to be 58 millimeters. The subject or patient is then seated in a comfortable position at the end of a table long enough to hold the optometer. The horizontal arm of the instrument is raised or lowered till the glasses are on the same level as the eyes of the patient, the nut in the arc in each slot is brought to the zero point, and by means of the thumb screw on the side the two carriers are also separated from or made to approach each other until the distance between the centers of the glasses, as indicated by the scale in front of the carriers, registers 58 millimeters. In other words, the instrument is so arranged that when the eyes of the person are in the primary position he can look straight through the glasses at an object six meters distant on the wall in front. It should be stated that the measurement of relative accommodation with *parallel* axes can be made almost as well without any special apparatus, and before the subject is seated in front of the optometer. Then he simply looks at the usual test types through glasses which are held in the ordinary frame.

However that part may be done, it is convenient to have at hand the table showing the meter angles with different degrees of convergence, and the blank referred to above.

Whether the optometer or a spectacle frame is used, at a distance of six meters in front of the patient there should be hung the series of ordinary test types properly illuminated. The examiner can manipulate the glasses with his left hand and make notes with his right. These numerous details being completed, we are ready to commence the examination. Let us suppose that the subject is an emmetrope. Of course there is no convergence when one reads the test types six meters distant, so we write zero in the

Date. Relative Accommodation. Case No.
Name.
Residence. Age. Base Line.
Right Eye V =
Left Eye V =

Meter Angle	Accom.	− Glass Overcome	Actual + Accom.	+ Glass Overcome		Actual − Accom.		Total of Relative.
0	0	− 3.25	2.95	0		0		2.95
1	1	− 3	2.59	+ 0.75		0.72		3.31
2	2	− 3	2.44	+ 1.5		1 38		3.82
3	3	− 2.5	1.95	+ 2.		1.74		3.69
4	4	− 2	1.46	+ 2.25		1.85		3.31
5	5	− 1.5	1.06	+ 2.5		1.90		2.96
6	6	− 1	.71	+ 3.25		2.34		3.05
7	7	− 0.75	.51	+ 4.5		3.08		3.59
8	8	0	0	+ 5.5		3.61		3.61
9	9	0	0	6.25	1.75	3.85	.94	2.91
10	10	0	0	7	4.5	4.02	1.81	2.21
11	11	0	0	7.25	5.5	3.65	2.60	1.05
12	12	0	0	7.5	7.55	3.46	3.38	.08
13	13	0	0	8	8	3.27	3.27	.0
14								
15								
16								
17								
18								

first space of this column. Over the next column in the table we write "Accommodation." The first entry which we make in this column must also be zero, for if

the emmetrope reads the test line marked six, it is evident that accommodation is entirely at rest.

Next, let us ascertain what is the positive part of the relative accommodation when the patient is looking at the letters six meters distant. For this purpose minus glasses are placed in succession before the eyes, commencing with the weaker and advancing to the stronger, till we find the strongest which do not distinctly blur the line which should be seen at that distance. These glasses represent approximately the degree of extra accommodation made by the ciliary muscles. Let us suppose that they are minus 3.25. This should be recorded. Accordingly over the third column we write "minus glass overcome" and in the first place in that column we enter -3.25. It has been said that this glass represents approximately the amount of accommodation exerted by the crystalline lens. It does not represent that accommodation exactly, however, for the reason that instead of being a part of the crystalline lens and having the same nodal points, it is in reality situated at a certain distance in front of the eye. That is, the arc of the slot in the carrier is at a distance of 0.03 from the nodal point of the eye. It is therefore necessary to ascertain what is the real amount of the accommodation exerted, when a minus 3.25 glass is placed three hundredths of a meter in front of the nodal point.

In the expression $\frac{1}{P - d} = \frac{1}{P' - d} + \frac{1}{F}$ (Chap. II., Sec. 3), we must remember that with parallel visual axes $P = \infty$, and also here, as later, the plus and minus signs for F give a minus.

Thus $\quad \frac{1}{P - d} = \frac{1}{P' - d} - \frac{1}{F}$

Hence $\quad \frac{1}{\infty} = 0 = \frac{1}{P' - 0.03} - 3.25$

$P' - 0.03 = 0.308$

$P' = 0.338$ meters.

Or expressing this distance as a reciprocal to show the lens value,

$\frac{1}{0.338} = 2.95$

21

This gives us 2.95 diopters as the real amount of the positive part of the relative accommodation exerted when the minus 3.25 glasses are in front of the eyes. That should be recorded. Therefore at the top of the next column in the prepared table we write "Actual positive accommodation" and in the first space in this column we enter 2.95.

The next step is to measure the negative portion of the relative accommodation by bringing convex glasses before the eyes. But it happens that the person we have selected has normal eyes. He therefore cannot relax the accommodation any farther when looking at an object with parallel visual axes, and any convex glass, however weak, blurs the types. But that fact should also be recorded. Consequently, over the next column in the table we write "Convex glass overcome" and enter zero in the first place in that column. Over the next column we write "actual negative accommodation" and in the first place in that column also enter zero.

Next let us take convergence at one meter angle. This time the subject looks not at the test types six meters distant, but at the uppermost of those already described on the optometer at a distance of one meter. Then, remembering that the distance between the eyes of the individual under examination is fifty-eight millimeters, we consult the table giving the angles of convergence and find that with a base line of fifty-eight millimeters, when the visual axes cross at one meter, there is a convergence of each of one degree and thirty-nine minutes. Accordingly, we loosen the thumb screw under the arc of one carrier, push the nut with the arc inward until the index marks about one degree and a half, and there make the nut fast. The same is done with the nut bearing the arc for the glass before the other eye. The centers of the two glasses are now in the line of the visual axes when the individual under examination is looking at the test type, one meter distant. We record as we proceed. As there is a convergence of the visual axes of one meter angle, in the second space of the first column we write one. As an emmetrope at that distance exerts naturally

an accommodation of one diopter, in the second space of the second column also we write one. We next find the strongest concave glass that can be overcome in the manner before described. Let us suppose that to be minus 3. This is written in the second space of the third column. That glass gives only the approximate amount of positive relative accommodation. It should be borne in mind that the object of the test is to ascertain the real amount of positive relative accommodation, and therefore we make use of our same formula, remembering that the distance P′ is a fractional part of the meter, and have

$$\frac{1}{P' - .03} = \frac{1}{\frac{1}{1} - .03} + 3. = 4.03$$

$$P' = \frac{1}{4.03} + .03 = .278$$

That is, with this lens (— 3.) before each eye, the distance P′ extends 0.278 meters from K. Expressing this in diopters (as the reciprocal)

$$\frac{1}{0.278} = 3.59$$

But the emmetropic eye without a glass, converged at one meter, of itself exerts one diopter of accommodation. So that the real positive part of the relative accommodation at one meter is not 3.59 diopters but

$$3.59 - 1. = 2.59 \text{ diopters.}$$

This is therefore entered in the second space on the fourth column.

Next we search the negative part of the relative accommodation with this degree of convergence. For that purpose convex glasses are tried in succession before the eyes, the strongest which will allow the test types at the distance of one meter to be seen distinctly indicating approximately the negative portion of the relative accommodation at that point. Let us suppose them to be + 0.75. In order to

ascertain the actual amount of the negative relative accommodation at that point we return to our formula (1) and substituting we have

$$\frac{1}{P' - .03} = \frac{1}{\frac{1}{1} - .03} - .75 = .28$$

$$P' = \frac{1}{.28} + .03 = 3.60$$

That is, with the lens 0.75 before the eye, the distance P' extends 3.6 meters from K. Expressing this in diopters (as the reciprocal)

$$\frac{1}{3.6} = 0.277$$

But as before, the emmetropic eye without a glass, when converged at one meter, naturally exerts one diopter of accommodation; so the real negative part of the relative accommodation at one meter is 1. — .277 = 0.72 diopter. This is recorded on the second line of the sixth column. The negative and positive portions added together give us the total range of the relative accommodation with the visual axes crossing one meter distant, and that amount—namely, 3.31—is entered in the second place of the last column.

Theoretically, measurements should be made successively with a convergence of the visual axes at two, three, or four meter angles, and at each step the proper entry made in the chart. Practically, it is better to vary this routine in several details. But to avoid confusion in this description it is assumed that each observation at the different meter angles is made one after the other, and recorded in succession.

We notice that the positive part of the relative accommodation grows gradually less while the negative part gradually increases. At last we reach a point where the crystalline lens cannot overcome any minus glass whatever. This, therefore, is the limit of the positive portion of the relative accommodation. In the case of our emmetrope, this occurs with a convergence of eight meter angles, hence in the third

column opposite that point we write zero and in the fourth column zero also. Then, testing with the glasses shows an ability to overcome plus 5.5, and making the correction for this according to the formula, we find 3.61 as the actual negative relative accommodation, or in this case the total relative accommodation is 3.61.

Beyond this point we have to deal only with the negative portion of the relative accommodation, but when we test this exactly, we find there is a certain range of plus glasses which our emmetrope can overcome. For example, when the test types are placed at this distance it is possible to relax the accommodation to such a degree as to see clearly with plus 0.75 and also in succession with plus 1, 2, 3, and so on up to plus 6.5. Evidently, therefore, there is a range of vision between these two points, and this is the range of the negative portion of the relative accommodation. These tests are made with convex glasses in a manner exactly similar to the tests already described, and in each case the correction showing the actual negative portion of the accommodation is calculated by the same formula which we have already used. The only difference in making this portion of the test is that in order to continue the record systematically it is necessary to subdivide the fifth and sixth columns below the point where the positive portion of relative accommodation has ceased to exist. We therefore draw a line down the center of the fifth and sixth columns. On the right side of this dividing line in the fifth column we write plus 1.75, and on the left side we write plus 6.6. Also, having made the correction for each of these according to the formula, and obtained for each the negative portion of the relative accommodation, we write the results respectively on the left and the right side of the line which divides the lower portion of the sixth column. Then we find the total range of accommodation by subtracting the lesser from the larger numbers in each horizontal line in the sixth column, and place the remainder in the seventh column.

The measurements are carried on in the same way with a convergence of nine meter angles, ten meter angles, etc., until at last we find a point where there is no range between

the two convex glasses which can be placed before the eye. In other words, there is no further range in the relative accommodation.

§ 5. **How to Plot Relative Accommodation.**—Donders found it convenient to represent relative accommodation and convergence in the form of curves or lines on the ordinary system of co-ordinates. In these, the horizontal line is divided into equal parts, each one of which from left to right represents one meter angle of convergence, from zero to about sixteen or eighteen. At each of these points of division a perpendicular is erected. The latter are also divided into equal parts, each of which, from below upward, represents one diopter of accommodation from zero to about sixteen or eighteen. At each of these points of division a horizontal line is drawn. These diagrams were elaborated by Bisinger (B 778) in Nagel's laboratory and are copied in many of the familiar text-books. At present, only a word concerning them is necessary. Thus if with one diopter of accommodation there is found to be one meter angle of convergence, we would indicate that by placing a dot at the junction of the first horizontal with the first vertical lines; if with two diopters of accommodation there are found to be also two meter angles of accommodation, we would indicate that by placing a dot at the junction of the second horizontal with the second vertical line to the end. In other words, our diagonal from the lower left-hand to the upper right-hand corner of the series of squares would represent both accommodation and convergence (Fig. 212). But if the positive part of the *relative* accommodation is recorded above the diagonal and the negative part below it, it is easy to see at once how a series of measurements is entered. These details which are apparently so self-evident are repeated, for the reason that such diagrams, at least in outline, ought to form a part of the clinical records in a considerable portion of our cases of anomalous action of the ocular muscles.

After the measurements are made and the results properly entered in the table, we can then construct our curves. Let us suppose that we wish to represent graphically the relative

accommodation of the emmetrope whom we have examined. We found with parallel visual axes that it was possible to exert an accommodation of 2.95. Therefore, commencing at the point marked zero on the squares, we count upward three squares, and just below that we place a mark. (Fig. 213.) From the sixth column of our table we find that the negative portion of the relative acccommodation is zero, consequently

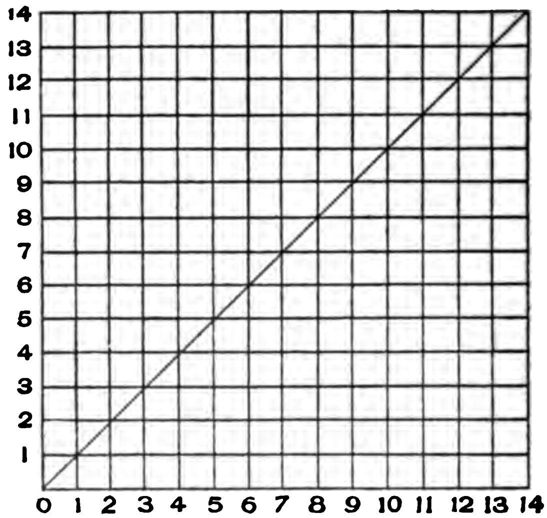

FIG. 212.—Diagrammatic representation of accommodation and convergence when they are equal.

the negative portion would begin at the zero point in the squares.

Next, with a convergence of one meter angle, we find the positive portion of the relative accommodation to be 2.59. Therefore, beginning at the point where the diagonal crosses the first horizontal line we count upward, and place a dot on the vertical line about half-way between the second and third squares above that point. With this same degree of convergence we find also the negative part of the relative accommodation is 0.72. Therefore, from the same point where the

diagonal cuts the first vertical line we measure down about three-fourths of the first square, and place a dot there.

The same process is followed of counting from the diagonal upward in squares or fractions of a square for the positive part of the relative accommodation, and downward in squares or fractions of a square for the negative part. When there is no longer any positive portion of the relative accommodation, the curve crosses the diagonal. Beyond that point there is only a range in the negative portion of

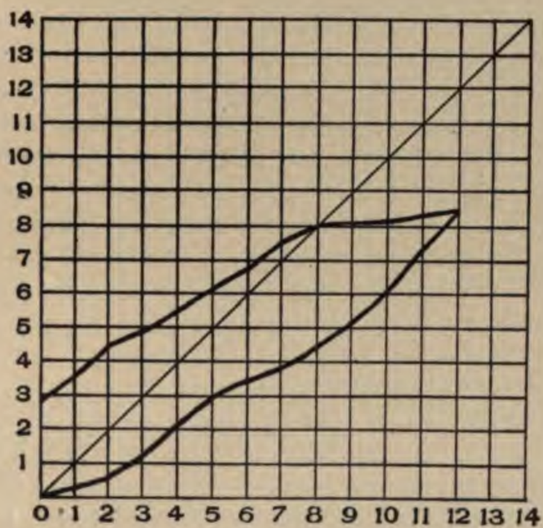

FIG. 213.—Lines showing the relative accommodation as plotted in a given case.

the relative accommodation. For both of these, we count down from the diagonal in squares or fractions of a square, that perpendicular line being chosen, of course, which indicates the proper degree of convergence. Finally, we come to a point where there is no longer any range even in the negative accommodation, and here there is but one dot or mark to make. Thus we find that we have the lines of the squares marked with a series of points, and it is only necessary to connect these points by a line in order to have before

us the curves desired. The plotting of the curves of the case just measured is shown in Figure 213.

When the individual under examination is an emmetrope, of course the second column of the table corresponds with the first—that is to say, at a distance of one meter the emmetrope exerts one diopter of accommodation, at two meters he exerts two diopters, at three, three diopters, etc. If, however, the patient is ametropic, that does not hold good. Thus, if we have to deal with a myopia of four diopters, such a person converges in the usual way, but does not exert any accommodation until the object which is fixed approaches nearer than four meter angles—that is, with a convergence of five meter angles there would be an accommodation of only one diopter. Then with a convergence of six meter angles there would be an accommodation of two diopters; with seven, of three diopters, etc.

When we wish to represent the relative convergence of such a myope by a curve, it is necessary that the diagonal should begin, not at the lower left-hand corner marked zero, but on the vertical line four squares *below* that, and extend diagonally upward and to the right as did the diagonal for emmetropia.

On the other hand, a hypermetrope has to make a certain amount of accommodation even for the distance. Therefore if we have to deal with a hypermetrope of two diopters, such a person with a convergence of one meter angle would evidently exert an accommodation of three diopters; with convergence of two meter angles there would be an accommodation of four diopters, etc. To represent the relative accommodation by means of a curve in such a case, the diagonal would not begin as in the case of emmetropia, but on the vertical line two squares *above* that point, and be extended diagonally and to the right in the same manner as in emmetropia. In either case the curve is constructed from the data in the table according to the same plan we have followed when dealing with emmetropia.

§ 6. **Other Methods of Measuring Relative Accommodation.**—It will be seen from the foregoing description that the general plan of these measurements is similar to that adopted by Donders and elaborated by Bisinger (B 778)

and Nagel (B 780). But it should be understood that it is not the only method nor is it the most accurate.

Another method of measuring relative accommodation was suggested by Pereles (B 787). The principle involved is shown in Fig. 214. L P, L_1 P_1 are the test objects, S and S_1 mirrors, and A and A_1 represent the position of the eyes. As the objects are moved in a curve toward the points II_1, the mirrors S and S_1, which are attached to the objects, turn outward, necessitating convergence just as in the reflecting stereoscope. The amount of convergence is therefore shown at once by the degrees on the arc through which the object turns.

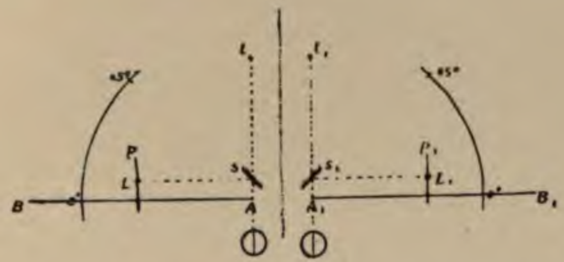

FIG. 214.—Pereles' arrangement for measuring relative accommodation and convergence.

Acting on this suggestion of Pereles', I had an apparatus constructed which was essentially the same, except as to a simplified and improved form of the object looked at. This arrangement is seen in Fig. 215. Probably the most exact instrument for this purpose is the one used by Hess of Würzburg, and special acknowledgment should be made at this point for the many suggestions obtained from him bearing on this part of the study. The principle involved in his apparatus is similar to the one suggested by Pereles, but differs from it in that the object to be observed is a point or two points of light as in the Schreiner test for accommodation. Moreover, instead of mirrors to mark the degree of convergence which the eyes make, in order to see the reflection of these points Hess used the

reflecting surface of a prism before each eye. The general arrangement of this apparatus is seen in Fig. 216. After reading his description, one of the instruments was ordered from the same maker, but the measurements with it were not satisfactory and later, after seeing the working of the

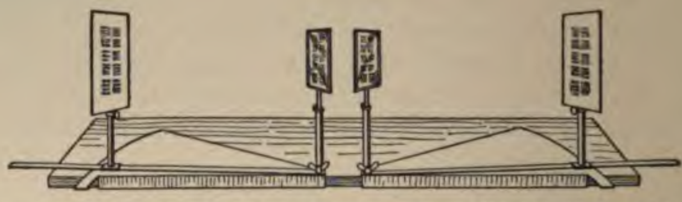

FIG. 215.—Sketch of Pereles' apparatus (as modified by the author) for measuring relative accommodation.

original instrument at the clinic in Würzburg, they were repeated. The difficulty is that the person who uses it must be well trained in laboratory work, as the results depend largely upon his ability to keep his eyes in the proper position (not an easy task), and also to determine exactly whether two points of light or one are visible, as in the ordinary Schreiner experiment. In a word, while this

FIG. 216.—Arrangement of Hess for measuring relative accommodation and convergence.

method is doubtless more exact than the others, it is not well adapted to clinical purposes.

Let us examine still further the apparent differences in the range of relative accommodation as measured by different methods. It should be understood that, although the earlier method suggested by Donders is still the simplest, and for

practical purposes the most convenient, on the other hand a source of error is undoubtedly present with tests made in that way. The fact is that the limits of the range of accommodation are not invariable. At one moment the person under examination may give one reply, and at another moment a reply a little different, depending upon the variation in the amount of the accommodation which he is able to exert at that instant, in his efforts to see the small letters more distinctly. For this reason the curves as given by Donders himself are somewhat inexact, principally because the test types used were imperfect. By employment of the photographed test types which have been here described, this error is very much lessened. But even with these, the tests show that instead of representing the limits of the positive and negative part of relative accommodation by means of a *curve*, the fact is that, in an exact sense, these limits of the positive and negative parts of relative range can be represented by straight lines. This has been dwelt upon at considerable length by Hess in his masterly contribution to this subject, which forms a part of the second edition of Graefe-Saemisch. The two lines which he gives as representing the positive and the negative parts of the relative accommodation are drawn by him as parallel to the diagonal.

From the foregoing it may be inferred that when we attempt to measure the amount of relative accommodation in any given case, the results depend to a considerable extent upon the method employed.

Thus if the subject is tested by looking through spherical lenses at a test object, which is practically of the same size for different degrees of accommodation, then, when we plot the results we obtain a well marked curve to represent the positive part of the relative accommodation, the convexity of this curve being directed upward, while the negative part of the accommodation is also represented by another curved line whose convexity is directed downward. Or, again, if we still use spherical glasses, but make the test object of carefully prepared photographic letters, as here described, then, when the results are plotted we obtain lines with less curve to represent the positive and the negative accommodation.

And finally, if we discard the spherical glasses, depending on the observation of a trained experimenter, and use only a spot of light for the test object, as in the instrument of Hess, we obtain a more or less straight line, parallel to the diagonal, which represents the relative convergence (Fig. 217).

This apparent difference is evidently dependent upon the

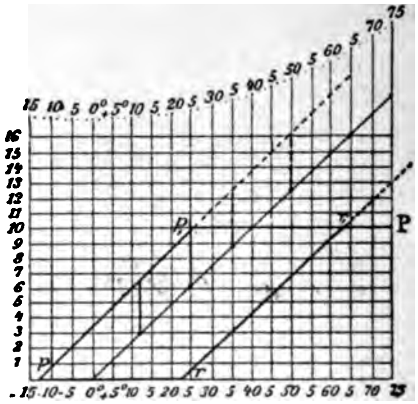

FIG. 217.—Straight lines showing the range of relative accommodation (Hess).

fact that when we test the positive and negative part of the relative accommodation by placing concave and convex lenses before the eye, no matter how accurately graduated the object which is looked at, the person under examination does vary somewhat this relative amount of the accommodation, while with the instrument of Pereles such variation is lessened, and with that of Hess it is still less.

But the practical fact is, that the concave and convex spherical glasses furnish us at once with a very simple method by which these tests can be made. For that reason they are to be preferred for clinical purposes. Practically, therefore, it makes but little difference whether we obtain as the result of our measurements a more or less curved line or a straight one to represent the relative accommodation. Indeed, it must be kept in mind that the real object of this long inquiry into

relative accommodation is not to determine any small theoretical question as to the value of methods or the degree of accuracy obtained with them. The question resolves itself into this: Is the positive part of the relative accommodation large or is it small with regard to the amount of convergence demanded by that individual for his usual work? If the positive part is large, then, other things being equal, that person has comfort; if it is not large, or if glasses will not make it so for him, then, other things being equal, he has discomfort. If the older methods of testing the relative accommodation with spherical glasses are sufficiently exact to define that condition, for practical purposes, then these methods should be preferred because they are simple, rather than because they are absolutely exact. The important bearing of this physiological fact will appear clearly when we come to the study of insufficient accommodation.

Finally we may ask, is this relation of accommodation to convergence exactly the same for all normal eyes? No. After making the measurements and plotting the curves for even a few persons, it becomes apparent that this depends upon the age or other factors, and that there are individual peculiarities modifying the form which the curve assumes. Indeed, this may differ somewhat for the same person at different times. How is it possible then to say whether the curve obtained for a certain individual at a certain time is entirely normal? It is impossible, just as it is impossible to say whether a certain individual at a certain time is or is not in "perfect health." But one condition is no more indefinite than the other. In spite of all these slight variations the data obtained by measurement of the relative accommodation are perfectly reliable for clinical purposes.

§ 7. **How the Range of Relative Accommodation with Parallel Visual Axes is Influenced by Age.**—The emmetrope whom we selected for measurement of the relative accommodation was still in early life, and we have found that he had $V = \frac{6}{6}$ and with minus 3.25 diopter glasses he could read test type at six meters quite as well as without any glasses. Now if we were to examine a large number of emmetropic persons under twenty or twenty-five, each one would

overcome glasses of about that strength. In childhood, say from ten to fifteen, there is not infrequently an ability to overcome minus three-and-a-half or occasionally a minus four, but more positive relative accommodation is exceptional. On the other hand, when we examine older persons, those over forty-five or fifty and beyond, then we find that this power of relative accommodation with parallel visual axes

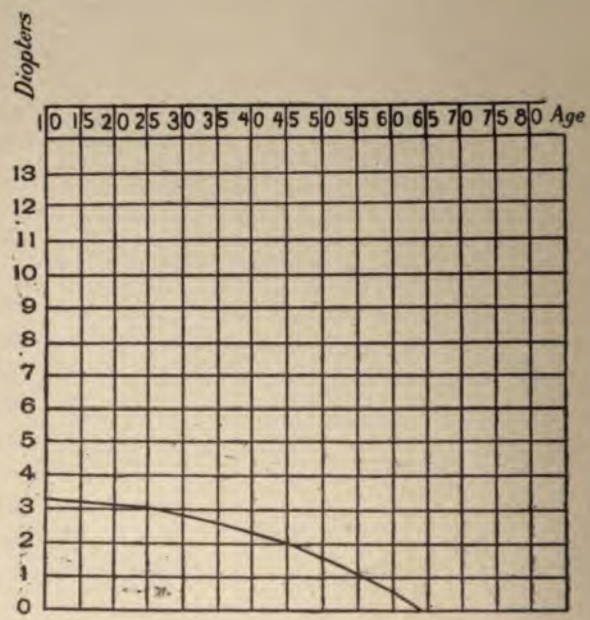

FIG. 218.—Curve showing the amount of positive part of the relative accommodation at different ages when the visual axes are parallel.

gradually decreases. On examining my notes of the amount of relative accommodation in young persons, especially in soldiers, and also the records of examinations which have been made of patients and others, it appears that a curve could be constructed which represents the gradual decrease with advancing age of the positive part of the relative accommodation with parallel visual axes. This curve is seen in Fig. 218. It shows that at ten or fifteen the positive part of the

relative accommodation may even exceed three diopters. From about fifteen to twenty or twenty-five it does not vary far from that amount, and at about thirty or thirty-five it begins to lessen. By forty it is hardly more than two. Another decade finds the power still less, so that by fifty or sixty or sixty-five the ciliary muscle has lost entirely its power of overcoming a minus glass when viewing the distant object.

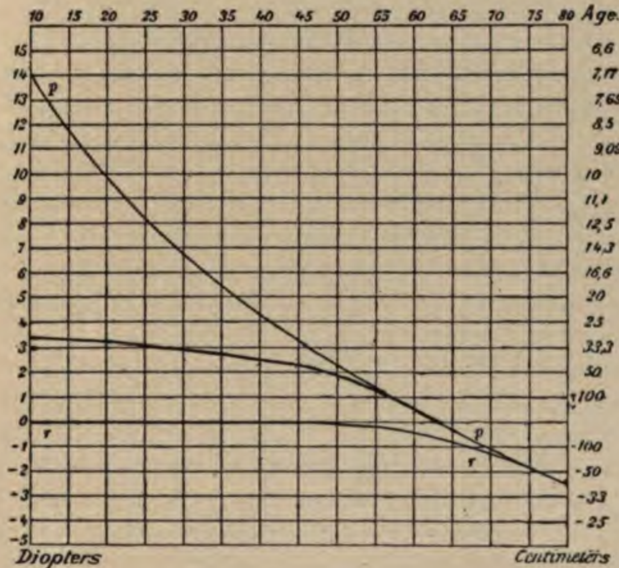

FIG. 219.—Representation of the change in the position of the far and of the near point with advancing age as given by Hess, together with the curve found by the author to represent the decrease in the amount of relative accommodation with parallel axes, also with advancing age.

This curve seems to be of importance because it represents what takes place not only in emmetropia but in ametropia. For, after a refractive error is corrected, if the ciliary muscle is still in normal condition, we find that with parallel axes this positive part of the relative accommodation remains practically the same. That is, in early life, if there is a hypermetropia of one diopter, then such a person can overcome

only a minus 2 or minus 2.5, etc. In order to show just how this curve compares with the curve for the change of the position of the near and the far point as first given by Donders, or as it is more recently elaborated by Hess, I have copied the illustration given by the latter, and inserted also, this third curve which represents the changes in the positive part of the relative accommodation with parallel visual axes. The three curves together are seen in Fig. 219.

§ 8. **How is Relative Accommodation Measured for Clinical Purposes?**—While the method which has been detailed for measuring relative accommodation shows what the plan is, and how it is possible to measure every part of a curve if we desire to do so, that procedure is evidently too technical and laborious to form any considerable part of an ordinary clinical examination. Although we are dealing now only with the physiological aspects of our subject, we may ask ourselves at this point how we can obtain some idea concerning the relative accommodation in a pair of eyes in the least possible time. It is not difficult. Indeed, most practitioners are accustomed to include an outline of this measurement in their routine work. For the superficial examinations with which we must be satisfied at the first visit of a patient, it is unnecessary to measure the base line or to attempt any correction for the distance of the glass in front of the eye. Suppose with the patient before us we have ascertained that he can read print 6. and 0.3 at the proper distances; naturally we wish to ascertain if there is any hypermetropia, and in doing so we use convex glasses in gradually increasing strength. If he does not accept any of these, we know that with parallel axes there is no negative part of the relative accommodation. If he does accept a convex glass, that shows that he is a hypermetrope and also the amount which is manifest, and that gives us evidently at the same time the negative part of the relative accommodation. Then we place minus glasses before his eyes — about minus 3 if he is an emmetrope, or if he is an ametrope varying their strength proportionately. This gives us at once the positive part of

the relative accommodation with parallel visual axes, or the sum of these two is the total range.

When testing the relative accommodation with convergence so as to obtain only the first general idea of the conditions present, it is unnecessary to use the optometer, or to measure exactly the degree of this relative accommodation with one or two meter angles of convergence. It is sufficient to determine at once the amount of relative accommodation with convergence at three meter angles, namely, at about the reading distance. For that purpose the test types which the normal eye can see at one-third of a meter are given to the patient, and having made sure that the distance at which they are held is about thirty-three centimeters, we place before each eye the strongest concave glass with which the patient can still read that print readily. This gives the positive part of the relative accommodation, understanding that we must subtract in that case three from the strength of the glass, because convergence at one-third of a meter itself necessitates for the normal eye an accommodation of three diopters.

In a similar way, by placing convex glasses before the eyes while the print is still held at one-third of a meter, and by ascertaining what is the strongest convex glass with which that print is seen, and again making a corresponding correction, we have the negative part of the relative accommodation with convergence at three meter angles.

Many clinicians are accustomed to make these rough tests of relative accommodation, and, as already stated, they often form a part of the routine examination at the first visit. In simple cases where one examination is sufficient, it is evidently a waste of time and energy to attempt any such tedious measurements of the relative accommodation as have been described here. But every practitioner knows how certain cases persist in returning. Moreover, the rough tests which we make at the first visit often show unmistakably that the difficulty depends on some anomaly of the accommodation. In such cases it is our evident duty to make use of every available means, to obtain all the data that we can concerning the accommodation, and in doing

this, much of the plan for measuring the relative accommodation of the physiological condition is useful also for clinical purposes.

§ 9. **Clinical Importance of Relative Accommodation.**— Attention was long ago called to the important relation which exists between the positive and negative part of the relative accommodation. Donders stated this in italics (B 260, page 114), saying that "*the accommodation can be maintained only for a distance at which, in reference to the negative part, the positive part of the relative range of the accommodation is tolerably great.*" This opinion has been corroborated by every student of ophthalmology during the last half century. Writers have expressed the important fact in terms more or less technical and clinicians of all grades have recognized it, usually without knowing it. It is, to refraction work, what the pole-star is to the mariner.

As it is essential to normal eyes to retain a "tolerably great" positive part of the relative accommodation, so is it in hypermetropia to keep a certain part of that in reserve as latent instead of using the total amount. Every time one prescribes a glass for presbyopia he recognizes this fact whether he thinks of it or not, for as the ciliary muscles gradually lose their power, the very object of the convex glasses is to keep the positive part of the relative accommodation thus "tolerably great." This important principle has an additional significance when we consider it not alone with reference to accommodation but in the relation of that act to convergence also. What it means, practically, is that a considerable excess of power of accommodation, such as we shall find in spasm of the ciliary muscle, and in what corresponds to that, as regards convergence—namely, esophoria—may exist without producing much discomfort, and is really of comparatively little clinical importance. On the other hand, we find that when the positive part of the relative accommodation is abnormally lessened, or in what corresponds to that as regards convergence—namely, exophoria—that condition is much more apt to give rise to

asthenopic symptoms of various kinds. They will claim our attention later.

In our studies of the pathological conditions of the muscles we shall find the most important and apparently the most frequent anomalies are those which involve the ciliary muscle. Therefore even in routine examinations, and at the first visit, it is desirable to determine whether the action of that muscle is normal or excessive, or insufficient. At least a general idea as to this power of the ciliary muscle is shown, as already stated, simply by placing thus a minus 3 glass before each eye and asking the patient to read again the distant test type. I have learned to regard this as *one of our most important tests.* For if, after the ciliary muscles have had a minute or two in which to adjust themselves, the person can still read as well as before, then we know at once, at least in a general way, that there is no imperfection in the power of the ciliary muscle, apart from convergence. If the person cannot overcome these or weaker minus glasses in proportion to his age or in proportion to his ametropia, then we at once suspect some insufficient power of the ciliary muscles. Even when such insufficient accom modation does exist, there may be little or no discomfort at near work, especially if the extraocular muscles are exceptionally strong or the general condition or the occupation of the individual unusually favorable. But ordinarily, if the positive part of the relative accommodation is insufficient with parallel axes, and also with convergence at one-third of a meter, and if discomfort and headache do exist, then that clue should be followed up. The examinations should be repeated, at first roughly, if desired, with convergence at one-half or one-quarter of a meter. But if this evidence points in the same direction, and if the discomfort continues even when other possible causes of the difficulty are eliminated, then it is usually worth while to make the data complete by measuring the base line and going through at least the essential parts of the examinations indicated. Of late years American ophthalmologists particularly have taken great pains to determine the condition of the extraocular muscles and have been so engrossed with these alone,

that physiological facts concerning the intraocular muscle which were demonstrated long ago, and which still are of th first importance clinically have been forgotten. It is well therefore, to establish on a firm foundation that part of ou clinical work, even though it necessitates this long anc rather wearisome discussion of relative accommodation.

DIVISION IV.

Relation of Convergence to Accommodation. Relative Convergence.

§ 1. **Definition.**— The amount of convergence which it is possible for an individual to exert or relax with relation to a given degree of accommodation is called the *relative convergence*. In Fig. 220 let us suppose the eyes to be converged and also accommodated to the point B. Then if adductive prisms of gradually increasing strength be placed before the eyes, the person, while retaining the same degree of accommodation, will be able to increase his convergence up to a certain limit. This degree is represented by the strongest prisms, with the bases outward, which he can overcome, and is the equivalent of converging to a point nearer than that to which the eyes are accommodated.

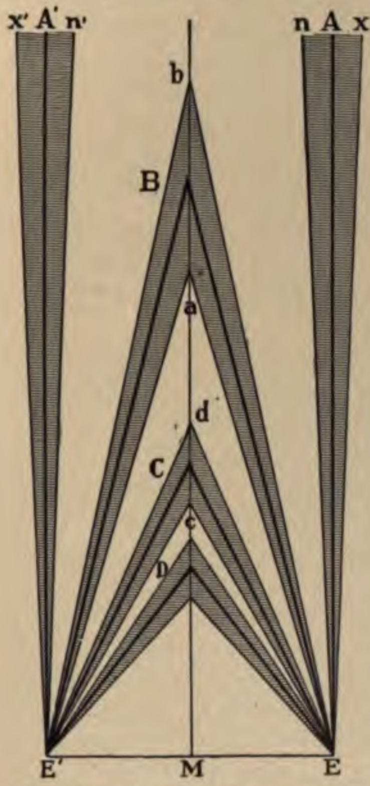

FIG. 220.—Diagrammatic representation of relative convergence with parallel axes and at three different degrees of accommodation.

If we wish to represent graphically this point of nearer convergence, we place it somewhere on the line MB—for example, at a. The distance Ba then represents the positive part of the relative convergence.

Again, let us suppose that while the person still accommodates for the point B, abductive prisms of gradually increasing strength are placed before his eyes; he will then be able to relax his convergence up to a certain limit—for example, to b. The distance B b then represents the negative part, and ab the total range, of relative convergence.

§ 2. **Desiderata for the Accurate Measurement of Relative Convergence.**—As certain requisites are necessary for the measurement of relative accommodation, so certain ones must also be provided for the measurement of relative convergence. We should have:

A. A visuometer.

B. A suitable test light in the distance and a slight change made in the optometer.

C. A table showing the size of the meter angle expressed in degrees with different lengths of the base line.

D. A table showing the angles of deflection caused by prisms.

E. Blanks on which the data can be conveniently recorded.

F. Other blanks, the co-ordinates, on which the curves or lines can be plotted.

It will be observed that we are already familiar with the first four of these desiderata.

The blanks for recording relative convergence require a word of explanation. These are quite as necessary and also as simple as those for recording relative accommodation. The first column on the left shows the convergence in meter angles. The second gives the amount of accommodation actually exerted, this being dependent on the kind and the degree of ametropia, if any exists. The third shows the strength of the adductive prisms which are overcome. The fourth gives the positive part of the relative convergence when expressed in meter angles; the fifth, the strength of abductive prisms; the sixth, the negative part of the relative convergence; the seventh gives the total range, or the sum of the positive and negative portion of the relative convergence. One of these blanks, filled out, is seen in the next section.

§ 3. **How to Measure Relative Convergence.**—The procedure for measuring relative convergence is similar to that for relative accommodation and in theory is very simple. That is, with a given accommodation the strongest adductive prism shows the relative near point of fusion, while the strongest abductive prism shows the relative far point of fusion.

An example will show this. Suppose we are measuring the relative convergence of an emmetrope whose base line is 58 millimeters. Also suppose that while viewing the test-light 6 meters distant he can overcome an adductive prism of 7 degrees before each eye, or, what is the same thing, 10 degrees before one eye and 4 before the other. On consulting the table (page 289), we find a prism of 7 degrees causes a deflection of 3.65°.

But from the table of convergence in meter angles (page 294) it appears that when an individual having a base line of 58 millimeters converges one meter angle, that, in degrees, is $1° \ 40' = 1.66°$. Therefore $\frac{3.65}{1.66} = 2.19$ is the amount of this positive relative convergence expressed in meter angles —that is, A E n or A′ E′ n′ (Fig. 220). Or again, suppose that our emmetrope, while viewing the test-light six meters distant, can overcome an abductive prism of 6 degrees before each eye, or its equivalent. Now from the same table of deflections we find prism $6° = 3.01.°$ Therefore

$$\frac{3.01}{1.66} = 1.8 = \text{A E x or A}' \text{ E}' \text{ x}'.$$

The same plan of course is to be followed with convergence at each meter angle. In making these measurements we use the optometer already described, turning the small box which is on the long bar so that the side which faces the patient presents to him a vertical line with a dot as the object for fixation.

These illustrations are sufficient to show the general principle involved and that this part is simple in the extreme. The adduction, as measured in degrees, is entered in the blank column opposite the point which shows the corresponding amount of accommodation. The abduction is

entered in the blank column, also opposite the figure for the corresponding amount of accommodation, and the total of the adduction and abduction is entered in the last column. For practical purposes this is quite sufficient.

The following is one of the blanks referred to in section 2, filled out with the data furnished by the examination of the relative convergence of the emmetrope already mentioned.

Date. Relative Convergence. Case No.

Name.
Residence. Age. Base Line.

Meter Angle.	Accom. Diop.	Adductive Prism Overcome.	Positive Convergence.	Abducive Prism Overcome.	Negative Convergence.	Total. in Meter Angles
0	0	7	2.1	6	1.8	3.9
1	1	7	2.1	6	1.8	3.9
2	2	6	1.8	7	2.1	3.9
3	3	6	1.8	6	1.8	3.6
4	4	7	2.1	7	2.1	4.2
5	5	8	2.5	7	2.1	4.6
6	6	7	2.1	8	2.5	4.6
7	7	6	1.8	9	2.8	4.6
8	8	5	1.5	10	3.1	4.6

§ 4. **Diagrammatic Representation of Relative Convergence.**—The earlier and more exact method is to represent the relative convergence on the same system of co-ordinates and in the same manner as we plot the relative accommodation. For the latter we have already seen that each one of the squares from below upward represents one diopter of accommodation, while each square from the left to the right represents one meter angle of convergence.

Evidently relative convergence can be counted in exactly a similar manner, only instead of reckoning vertically from a certain point of the diagonal we count horizontally from that same point of the diagonal. So many squares to the right show the positive part of the relative convergence, or so many squares to the left show the negative part. (B 780, p.

98.) The reason for this is, that normal convergence with maximum accommodation (positive relative accommodation) is of the same character as normal accommodation with minimum convergence (negative relative convergence), and the reverse. We might therefore expect that with each meter angle of convergence, if we count from the diagonal to the right, on the abscissa, we would find that the positive amount of the relative convergence would coincide with the relative accommodation. But in reality that is not always the case, as Nagel himself has shown. The fact is that if we

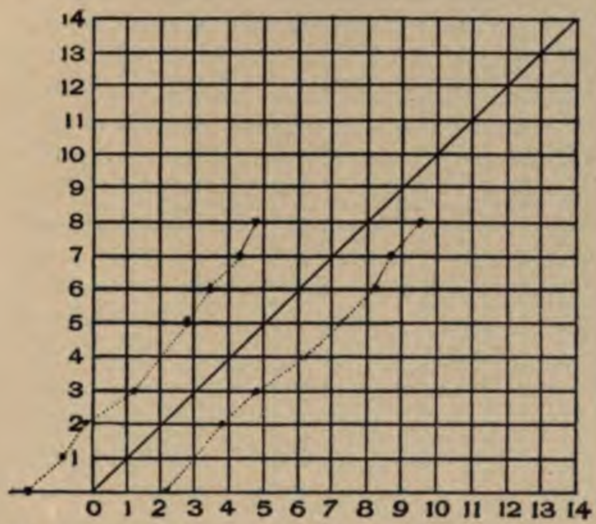

FIG. 221.—Lines showing the relative convergence as plotted in a given case.

attempt to plot the relative convergence in a given case,—for example, in that of the emmetrope referred to,—we find that the lines representing positive and negative convergence are often almost parallel to the diagonal in our system of co-ordinates. Thus to plot the relative convergence with parallel axes, we would represent the positive part on the right of the first horizontal line—that is, about 2.1 squares from the zero point, whereas the negative portion would be represented on a continuation of that line to the left, a distance of 1.8 squares. With one diopter of accommodation,

the positive part of the relative convergence would be at a distance of 2.1 squares from the right of the diagonal, and the negative portion at a distance again of 1.8 squares to the left of that diagonal, when that second abscissa is extended that distance to the left. The other amounts of positive and negative relative convergence are indicated in the same way. Figure 221 shows how the figures given in the above table are plotted on the system of co-ordinates.

Relative convergence may also be represented by means of a diagram. This is seen in Fig. 219. The amount of normal convergence is shown by a heavy line passing from each eye to the point for which each is also accommodated. A pair of lighter lines converging toward a nearer point indicates the positive part of the relative convergence; another pair of lines converging toward a more distant point, the negative part; and the space between these two lines then shows, of course, the total range of the relative convergence. When this space is shaded it makes this range rather more apparent.

This graphic representation is very convenient in showing at a glance what is intended. It has the disadvantage that it cannot be carried beyond more than three or four meter angles without causing confusion. It is therefore employed to give a general view of relative convergence only when that is for a few meter angles, as in the figure mentioned.

§ 5. **How is Relative Convergence Measured for Clinical Purposes ?**—The foregoing shows us how convergence is measured and recorded with different degrees of accommodation, but here also the objection arises that any such detail is not possible in the routine of office practice, and although we have not yet reached the clinical aspect of our subject, it is well to ask here, as we did in regard to relative accommodation, how we can obtain quickly and easily some idea of relative convergence in a pair of emmetropic or ametropic eyes. The process is simple. For these rough tests we do not need a visuometer or optometer or special blanks of any kind. We require only the usual test-

light or object in the distance, and the Graefe dot and line drawn on the test-type card. It is part of the routine examination by nearly every practitioner to ascertain the amount of adduction and of abduction for the far point. This is nothing more than the range of relative convergence with relaxed accommodation. In routine cases it is of course only necessary to ascertain the relative convergence with accommodation thus relaxed, and then we proceed at once to the relative convergence and divergence with accommodation at one-third of a meter. If these rough tests at the far point and at one-third of a meter show that there is any peculiarity in the range of relative convergence, a similar test is made when the dot and line are held at a distance of one-fourth or one-fifth of a meter, providing the opportunity is then afforded for so much detail. In most cases it would be an evident waste of time to map out its entire range, but on the other hand, in those exceptional instances, especially of esophoria or exophoria, where there is an evident fault in the power of convergence, accurate measurement is not only desirable but a necessity, if the clinician expects to base his diagnosis upon reliable data.

§ 6. **The Clinical Importance of Relative Convergence** is undoubtedly as great as that of relative accommodation. So much has been said already concerning the latter that no elaboration of this point is necessary. Suffice it to mention that the clinical relations of convergence in this and in other forms will be met with at every turn and no phase of our subject is worthy of more careful study.

DIVISION V.

Relation of both Accommodation and Convergence to Torsion or True Torsion with Convergence.

§ 1. **Definition.**—Torsion with convergence is the tipping outward of the upper ends of the vertical axes (true torsion) which accompanies convergence. This is in proportion to the amount of convergence and varies according to the inclination of the visual plane. It is ordinarily only of a slight degree.

§ 2. **Appliances for Measuring Torsion with Convergence.**—When studying the first group of associated movements we were led to consider the torsion made when the visual axes are in the primary position, and we became acquainted with the appliances used by Hering, Donders, and others for studying this group of movements. It was mentioned then that the same appliances were also used by these earlier students to determine the torsion which occurs in the act of convergence. Before considering their use in this way, it will tend to clearness and save repetition to make one or two preliminary observations which apply to them all.

(*a*) Classification of the appliances. At the outset, it is desirable, if possible, to clear up some of the confusion caused by the fact that different students have given different names, like the "isoscope," "discs," "clinoscope," etc., to different instruments all of which are intended to measure the tipping in or out of the vertical axes. Stress has already been laid on the fact that the 'phorias are all of a passive nature, and as the *clinoscopes* measure only degrees of cyclophoria it is well to distinguish these instruments as a class from the *converging clinoscopes*, or the *tortometers*, which measure the cycloduction accompanying convergence. It is true, most of the tortometers are also clinoscopes, but all clinoscopes are not tortometers.

(*b*) Determination of the plane in which the visual axes lie. In the definition of torsion with convergence it was stated that the degree of this varies according to the inclination of the visual plane. Evidently it is desirable to understand how this visual plane can be determined, at least roughly. Probably the simplest way and the one which is suitable for measurements made with all of the earlier instruments is the plan described by Le Conte. A horizontal line is drawn on the wall opposite the observer and at the same height from the floor as his eyes. Then the observer closes the left eye, and with the right follows the line on the wall until the vision is obstructed by the root of the nose, tipping the head up or down until the line seems to touch the nose at its point of greatest recession. The same experiment is repeated with the other eye. This line on the wall then practically corresponds with the horizontal plane.

Next we wish to determine the visual planes which pass through the nodal point of both eyes and which are inclined to the horizontal plane below or above it at certain definite angles. This can be done in two ways. One is by arranging the Helmholtz bit so that the head can be tipped backward at certain angles. That gives the planes which are inclined below the horizontal at certain angles. Or, by tipping the head forward we obtain the angles inclined above the horizontal. It is possible, however, to determine the planes of the visual axes in another way. On the wall which is in front of the observer, and at a distance of at least six meters, we lay out vertically a tangent scale, the radius of that arc being the distance from the wall to the observer, and the nearest point on the scale being that at which the horizontal visual plane intersects this vertical tangent scale at right angles. At points of say ten degrees apart, above and below the horizontal plane, horizontal lines are drawn across the wall. By following these lines along, first with one eye, and then with the other, until the view is obstructed by the nose or by the brow, we determine the position of a given visual plane in the manner described for determining the position of the horizontal plane.

It is worth while to glance thus at the methods which have

been used for determining these different planes in order that we may obtain more definite data concerning torsion with convergence than those which have been found by earlier investigators, and upon which we now rely. It is evident, however, that any such methods are adapted to the laboratory only. It is for this reason especially, that it seemed desirable to adapt the tortometer to the ordinary perimeter, in order that when the arc is vertical the instrument can be placed at once in any visual plane desired. This has been done and the appliance will be described in a subsequent section.

(*c*) Only young subjects or those with comparatively good power of convergence and accommodation are suitable for the measurement of torsion with the higher degrees of convergence. This statement is self-evident. It is true that we can measure the torsion which occurs with accommodation up to the point of clear vision for that individual as well as for one who has a large range of this kind. It is also true that by placing convex glasses before the eyes the difficulties in the problem can be to a great extent eliminated, but as soon as we thus change artificially the degree of accommodation which naturally goes with a corresponding amount of convergence, we bring still another factor into the problem and make the results more uncertain. Therefore in seeking for a basis of physiological experiment we require always young subjects whose power of accommodation and convergence is still large.

(*d*) In all these measurements of torsion it should be understood that the methods are more difficult than the measurements of relative accommodation or relative convergence, and the results are therefore more liable to error. Even when we have the best of laboratory appliances and also subjects well trained to physiological experiment, it must be confessed that the measurement of torsion is by no means an easy matter. Evidently, therefore, measurements which are made in the consulting room and upon the average patient are often far from satisfactory. It is a field in which improvement in method is still much to be desired. On the other hand, such facts as we have, indicate that this factor in binocular vision is quite as important as is accommodation or con-

vergence. While this frank statement of the difficulty of its measurement is necessary, that should not deter us from efforts to be more exact in this part of our examinations.

The different appliances with which this torsion can be measured are:

(A) The arrangement suggested by Hering (Fig. 182). In studying torsion which occurs with parallel visual axes the vertical lines are of course placed at a distance of six meters or more, but when convergence is brought into action, its degree is measured either by approaching the blackboard or by having a point placed between the observer and the vertical lines so arranged that the distance from this point to the observer can be easily measured. Hering's method is of special interest for the reason that it was followed by Landolt in the studies which he made of torsion with convergence. His results will be given later.

(B) The appliance of Donders which he called the isoscope was used for the purpose, as we have already seen, of determining the amount of tipping which the vertical axes make while the visual axes are in the primary position. But what interests us here is that the torsion which occurs with convergence was described by Donders at the same time that he described and figured the isoscope. His method, although slightly different from those of Hering and of Volkmann, shows in general that the differences in the results are only slight.

(C) Volkmann's discs. While studying the position which the vertical axes tend to assume when the visual axes are in the primary position (Chapter II, Section 5), we found that Volkmann's discs could be used to advantage in making these measurements. In Stevens' later model of his clinoscope (Fig. 178) he shortened the tubes to permit more convergence. But as sufficient convergence of the tubes could not be obtained in that way, it seemed desirable to mount the same discs in quite another manner (Fig. 179). As we were then considering only the torsion which can occur with the visual axes in the primary position, no mention was made of the method of measuring the torsion which

This method of estimating the amount of torsion with convergence was simple but tedious. It was necessary to draw one set of squares after another, the lines which composed one square being inclined to those of the other squares at a known angle. When these lines appeared to the converging eyes to be vertical,—that is, when the angle at which the lines actually converged upward was balanced by the angle which the vertical axes of the eyes converged downward, the degree of torsion was known. An example of one of these trial figures given by Le Conte is shown in Fig. 223.

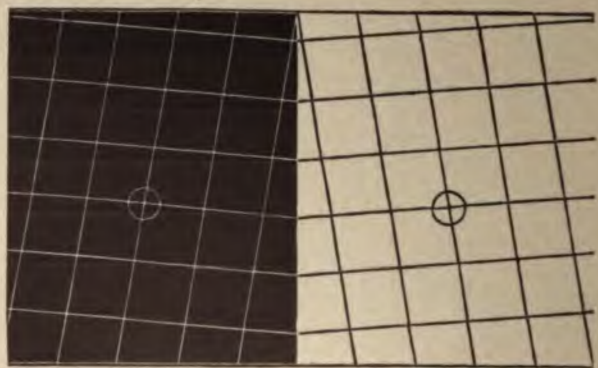

FIG. 223.—Lines drawn at an angle in order to have them appear vertical when the eyes are in extreme convergence.

(E) **Author's Arrangement of Le Conte's Squares (the Tortometer).**—While Le Conte's squares constituted the best device up to his time, for determining torsion with a given degree of convergence, he left much to be done in simplifying the method. After many vain attempts to obtain with these squares data which were fairly constant, a number of improvements in his plan gradually suggested themselves. They took the form of a device for measuring the degree of torsion which might be called a tortometer. As this is nothing more than a mechanical adaptation of Le Conte's squares, the amount which the upper ends of the vertical lines of the squares converge corresponds to the amount which the upper ends of the vertical axes of the

eyes diverge. In the arrangement referred to, the object looked at is not exactly the two sets of squares, but instead, it has been found more convenient to use, before one eye, vertical black lines on a white ground, and before the other, vertical white lines on a black ground. All the horizontal lines except one are omitted, for even a trained observer may be confused by their presence. By a simple mechanism

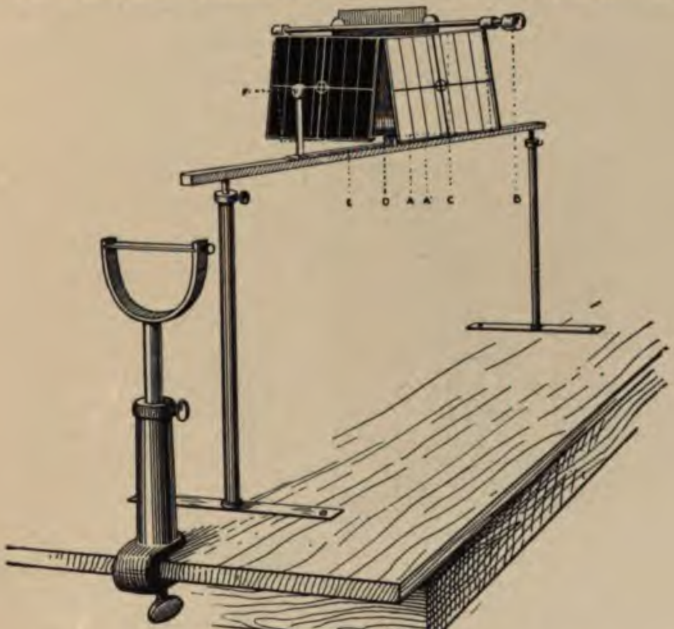

FIG. 224.—Tortometer of the author arranged for measuring torsion in the horizontal plane.

(Figs. 224 and 225) these vertical lines may be tipped into any position desired and the angle between them can then be read off on the short arc (D). In order to accomplish this, each of the two cards is fixed in a frame of brass about eight or ten centimeters square. The upper edge of each of these frames is attached to a band (C) of flexible steel, one centimeter wide and two or three millimeters thick. This band, in turn, is connected with a horizontal rod which has a nut (B) on the right side. By turning this nut,

the angle between the lines can be increased or diminished. The point F, at which the visual axes are converged, is a ball which, being attached to a support, can be slid backwards and forwards any distance desired.

This whole arrangement may be attached by a slot on its posterior surface to any support. One such support is the horizontal bar already described as a part of the optometer for measuring relative accommodation and convergence (Fig. 224). When mounted in this way, we measure with it the torsion with convergence in the horizontal

FIG. 225.—Tortometer of the author arranged for measuring torsion in various planes.

plane. Or the two cards thus mounted can also be attached to one of the carriers on the concave surface of the ordinary perimeter, and we can then measure the torsion with convergence in planes inclined either below or above the horizontal (Fig 225).

The method of measuring torsion with this arrangement is simple. First, the head is brought to the proper height and steadied by resting the teeth on the wooden bit, or a head-rest with the forehead piece can be used.

Second, the horizontal plane of the eyes is determined in the manner described on page 349 either with the assistance

of a line drawn on the wall opposite the observer, or by some substitute for it.

Third, the person is then directed to look at the fixation point (F) (whose distance from the eyes can be changed at will) until a part or all of the vertical lines on the right side appear to be on the left, and the reverse.

Fourth. When this is accomplished, the lines when actually vertical seem to converge downward if the eyes are normal. Then, by turning the nut (B) the cards are tipped gradually, so that the lines actually converge upward. When the point is reached where they seem to the observer to be vertical, the examiner reads off on the arc (D) the angle which the two sets of lines make with each other. Half of that arc is the amount which the upper end of each eye tips outward, when converged to the distance which the fixation point F is from the center of the base line.

The amount of torsion present when the eyes are elevated or depressed can be measured as easily with the tortometer here described as can torsion in the horizontal plane. As a preliminary step, it is necessary to bring the center of the tortometer (that is, the point which is in the middle of the adjoining edges of the black and white cards) to correspond with the center of the arc of the perimeter (Fig. 225). The four succeeding steps are the same as those described for measuring torsion in the horizontal plane. After that has been determined for a certain degree of convergence, as regulated by the position of the point for fixation (F), the cards are slid upward on the arc a certain distance, say ten degrees, and the reading taken; afterwards at twenty, at thirty degrees, etc.; or the cards are slid downward and similar readings taken at successive points.

In regard to the actual usefulness of this arrangement it must be said that in spite of all the care which can be exercised in its construction, and its use even by an intelligent patient, the results obtained are not always constant. This may be due to the fact that different persons, even when about the same age, probably make slightly different degrees of torsion. It must also be said that even the same person will show at different times a perceptible difference in the amount of torsion,

no matter in what way it is measured. These sources of error should be mentioned. But on the other hand, they are not greater than those which occur with the measurements of accommodation or of convergence, nor those which we find in any similar physiological experiments.

As the lines on these cards are inclined more and more, the question arises of how we can measure the angle which they (and the cards) make with each other. It should therefore be referred to.

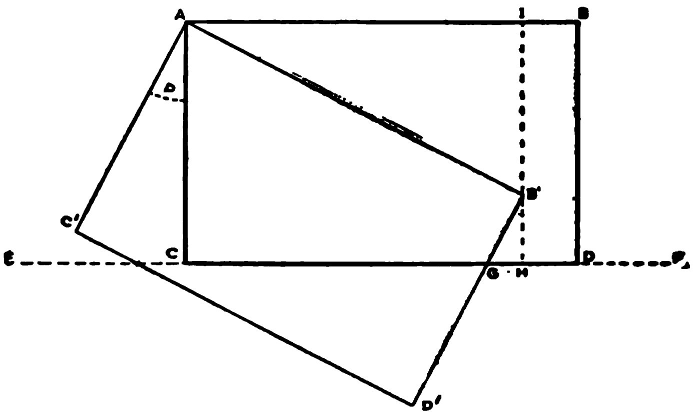

FIG. 226.—Diagram showing how to calculate the angle at which the lines converge in the tortometer.

Let ABCD, Fig. 226, be the card carrier in its primary position, and AB'C'D' be its position after rotating through an angle P. To calibrate an instrument of this kind, the simplest way is to insert a card back of the card carrier ABCD, then, taking a sharp pencil and using the bottom (CD) of the card as a ruler, draw a line ECDF. It is obvious that when the card carrier has moved to a new position, making any angle, as P, with the old one, that the side B'D' will cut the line EF at some point, as G. Then, setting the card carrier at different angles, mark off different points on EF for the various angles.

A more accurate way is to calculate first what the distances on CD are for different angles. To do this, from B' drop a line perpendicular to AB and extend it to CD, then since CD is parallel to AB, HI is perpendicular to CD. The angle GB'H is equal to the angle C'AC, which equals P, since the sides of the angles are mutually parallel and run in the same direction.

Let any distance, as GD, be denoted by K. Let the side B'D' of the right angle be denoted by L, and let the distance AB, from the center of rotation to the farther end of the card carrier, be denoted by M.

Then

$$K = GH + HD \qquad (1)$$

$$GH = (HB')(\tan P) \qquad (2)$$

$$HB' = HI - IB = L - IB' \qquad (3)$$

$IB' = (AB')(\sin IAB') = (M)(\sin IAB')$, but the angle IAB' = the angle $C'AC$, since their sides are mutually perpendicular.

Hence

$IB' = M \sin P$. Put this value in (3).

$HB' = L - \sin P$. Put this value in (2).

$GH = (L - M \sin P) \tan P$. Put this value in (1).

$$K = (L - M \sin P) \tan P + HD \qquad (4)$$

To find HD, observe that

$HD = IB = AB - AI = M - AI = M - AB' \cos P = M - M \cos P$. Put this value in (4).

It is unnecessary to follow the intermediate steps of this calculation, and it must suffice here to say that we arrive ultimately at the expression:

$$K = \frac{M \cos P - M \sin P}{- \sin P}$$

Having thus glanced at the structure and working of several appliances used for measuring torsion with convergence we naturally ask which among them all is the best. Unfortunately no one instrument or method can be selected as being superior in every way. For persons of intelligence the method of Le Conte is not only the most reliable but the most expeditious. For that reason the attempt was made to simplify it, and adapt it not only to laboratory but to clinical use.

§ 4. **How Great Is the Torsion with Convergence in the Horizontal Plane?**—It will be easier to understand the results of these measurements, no matter in what way they are made, if it is repeated that the amount of torsion with convergence depends upon two distinct factors. One

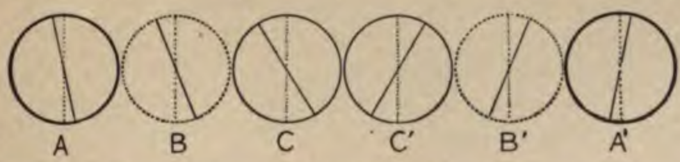

FIG. 227.—Schematic view of the position of the vertical axes with increasing convergence in the horizontal plane. The actual vertical is drawn with a dotted line. A A' position with parallel visual axes; B B' with moderate convergence; C C' with extreme convergence.

is the *amount of convergence and of accommodation* which is exerted by the individual, and the other factor is the *position of the plane* in which the visual axes lie—that is, whether they are in the horizontal plane or in a plane

inclined below or above the horizontal. In considering the results of these measurements we naturally ask first:

What amount of torsion does each eye undergo when the visual axes lie in the horizontal plane and cross in the median plane?

This has been found by Landolt's measurements to be as follows

Convergence in Degrees.	Torsion in the Horizontal Plane.
5	1 30′
6	1 45′
7	2 5′
8	2 5′
9	2 10′
10	2 30′
11	2 40′
12	2 55′
13	3 20′
14	3 30′
16	3 55′
18	4 50′
20	5 40′
25	5 52′
30	6 50′

The gradual tipping of the upper end of the vertical axes as the object approaches in the horizontal plane is seen in an exaggerated form in Fig. 227.

§ 5. **How Great Is the Torsion with Convergence above or below the Horizontal Plane?**—We have just seen that as the convergence in the horizontal plane increases, the upper end of the vertical axis of each eye tends to tip outward. We come now to another fact—namely, that the tipping outward of the upper end of the vertical axes usually increases as the plane of the axes of vision is elevated. It is true that when we examine any of these series of measurements, like the data given by Landolt (B. 820, p. 662), for example, we notice that the increase in the amount of tipping is not always in proportion to the amount of convergence. This is apparently contradictory, but any one who is familiar with such laboratory measurements appreciates that at least some irregularity in the

results is the rule rather than the exception. No matter how intelligent the subject of the measurement may be or how accurately the measurements are made, such irregularities are apt to occur. It is also true that the experiments made by different investigators give slightly different results, but they accord sufficiently to show that Landolt's figures furnish a standard by which to measure the amount of torsion which is normal. Accordingly this part of his table is reproduced below.

	Above the Horizontal Plane.			Below the Horizontal Plane.				
Convergence in degrees.	25	20	10	10	20	25	30	40
5	2	1 5′	1	1	1	—	1	1
6	2 30′	2	1 5′	1 20′	1	—	1 10′	1 30′
7	3	2 30′	2 30′	1 30′	1 30′	1	1 30′	1 30′
8	3	2 20′	2 20′	1 30′	1 30′	1	1 30′	1 35′
9	3 10′	2 20′	2 30′	1 40′	1 30′	1 15′	1 20′	1 35′
10	4 20′	3 30′	3	2	1 40′	1 30′	1 50′	1 40′
11	5	3 30′	3	2	1 50′	—	2	1 5c′
12	5	3 40′	3 10′	2 10′	2		2	1 30′
13	7	3 40′	3 40′	2 30′	2		2 10′	1 30′
14	7 30′	4	3 40′	2 40′	2 5′		2 20′	1 30′
16	8	5 30′	4 5′	3	2 10′		2 30′	2
18	9	5 30′	5	4	3		2 50′	2 30′
20	11	7 30′	6	4 30′	3 30′		3 10′	2 45′
25	15	8	7	4 50′	4		3 30′	2
30	16 30′	10	8	5 50′	4		4	1

§ 6. **How to Plot Torsion in a Given Plane.**—This can be done with the ordinary system of coördinates in the same manner as we have already plotted relative accommodation. A convenient method is to have the ordinates represent the increase in convergence (and accommodation), and the abscissas represent the increase in the amount of torsion from zero to eight or ten degrees. As it is possible in laboratory work to estimate the amount of torsion to half a degree, as Landolt has done, each space between the abscissas can, for such purposes, be counted as thirty seconds. For clinical purposes, however, such accuracy is impracticable.

§ 7. **Relative Torsion** is the amount which the upper end of the vertical axes tips in or out beyond the amount which normally occurs with a given degree of convergence in a given plane.

Just as we have found that we can measure a positive and a negative portion in the range of accommodation with relation to convergence, and the reverse, so can we also discover a positive and negative portion of the range of torsion with relation to both accommodation and convergence. These measurements can be made, approximately at least, with the converging clinoscope (Fig. 179), entire diameters being used on the discs.

§ 8. **Desiderata for Testing Relative Torsion** are:

A. A tortometer (converging clinoscope).

B. A table showing the angle of torsion with a given degree of convergence in a given plane (Landolt).

C. A table expressing degrees in terms of the meter angle.

D. A blank on which to enter the measurements made.

The heading for these blanks should have space for the number, name, etc. It should also indicate whether the measurements made are in the horizontal plane, or if these are made in any plane above or below the horizontal, that should be stated also. The first column to the left indicates what is the degree of convergence as expressed in meter angles. The second column shows what the convergence is in degrees. Knowing the base line it is easy to ascertain what that number of degrees is from the table, page 294. The third column shows what the normal torsion is with that degree of convergence. When this is expressed in degrees we can copy it directly from Landolt's table.

In the fourth column we enter the amount of positive relative torsion. This is obtained, as has been already stated, by finding first what is the total amount which the vertical axis seems to tip outward. From that amount we deduct the amount of torsion which we find from Landolt's table to be the normal amount of tipping outward for that degree of convergence, and the difference between the two is the positive part of the relative torsion. In a similar

manner we obtain the negative part of relative torsion. That is entered in the fifth column. The last column shows the total amount of relative torsion. This, of course, is obtained by adding together the positive and the negative part. It is well to leave a portion of the blank on which to enter memoranda relating to these different measurements.

§ 9. **Imperfection of our Data.**—This reference to relative torsion and to desiderata for testing it has been made rather for the sake of completeness than because of the possibility of great exactness with the methods now at our command. The aim has also been to indicate a plan on which further studies of these subjects could be prosecuted.

But it must be admitted that our actual data concerning normal torsion with convergence are unfortunately few and imperfect. Still more meager is our knowledge of relative torsion with convergence. But painstaking measurements of even moderately intelligent subjects give results which are fairly constant, and it is not too much to hope, therefore, that with improved appliances this phase of our subject may become clearer, as its apparent importance is more fully appreciated.

§ 10. **The Object of Torsion with Convergence** is not clearly understood. There is no apparent reason, for example, why, when we look at a near point, accommodation and convergence should not be sufficient without this additional wheel-like motion. Indeed, it is difficult for us to understand how that can occur without producing some diplopia. Various studies of this question have been made, and they indicate, in general, that the torsion which occurs with convergence does assist in producing stereoscopic vision. There still remains, however, very much for us to learn concerning this subject. Although we do not understand the reason for this motion, the practical fact remains that when it is disturbed either purposely or by pathological conditions, the results then appear of importance.

§ 11. **What Happens if Torsion with Convergence is Artificially Disturbed?**—We have thus far no means of controlling torsion, as readily as cycloplegics or myotics

control the accommodation, or as prisms affect the convergence. We have already seen, however, that even with parallel axes any disturbance of the rotation of the globe on its fore-and-aft axis, as when made in the interest of single vision, is accompanied by discomfort. If we make use of a clinoscope so constructed as to permit sufficient convergence, it is possible to show in a still more marked degree how great is the discomfort produced by even a slight disturbance of torsion. With this, the experiment can be made as for parallel axes, of gradually turning the vertical lines too far out of place. The effort at torsion which the eyes make to fuse these lines usually shows itself in a sense of discomfort which is very noticeable. The disturbing effect of the torsion is familiar to every ophthalmologist when certain glasses are prescribed, especially if these are cylinders of considerable strength. The patients often complain that vertical lines diverge downward or upward, thus making a page seem broader above or below, or various similar distortions may occur. After a time the eye and perhaps the brain, or both, adjust themselves to this new position, and the annoyance ceases. In like manner, in cases of simple astigmatism where accommodation and convergence are normal, proper corrective glasses relieve the discomfort. If, now, the axis of one or both cylinders be changed, even a few degrees, a considerable amount of inconvenience is often experienced, due, so far as we know, to an unnatural torsion, as the eye tries to adapt itself to the new axis of the glass. The light circular frames which are sold with cylinders and can be lent to patients are very useful in making these interesting and instructive experiments.

The manner in which torsion can be disturbed is also seen by a simple example. Let us suppose that we have to do with a marked degree of astigmatism. When measuring its degree and its angle, we test the eyes with objects placed in the horizontal plane and with the visual axes parallel. Then we prescribe glasses which, under such circumstances, give the best correction. When, however, that same person exerts a very considerable amount of

convergence in the same horizontal plane, or when he lifts the eyes so that the visual axes are in a plane which is inclined to the horizontal plane at a considerable angle, then, in the natural torsion which accompanies either of these movements, the angle at which the glasses were set no longer coincides with the angle of the astigmatism of the eyes. There are several occupations which require the elevation of the eyes in this way, as, for example, when a clerk is obliged to look up to read labels on shelves, or when an accountant, bending the head down toward one book which is immediately in front, looks occasionally at another book situated also on the same table but a little distance away.

§ 12. **What is the Clinical Value of Any Such Facts or Measurements?**—This question may well be asked, especially in view of the small amount of torsion which can be detected, even at the maximum. From the foregoing it would appear that in practice:

1st. We must take torsion into account, together with accommodation and convergence, as one of the three factors which contribute to comfortable vision at the near point.

2d. In ordinary near work which requires the individual to look down at an angle of 35 or 40 degrees, and to converge at a point about 30 centimeters distant, almost the minimum amount of torsion is ordinarily demanded.

3d. Even a slight disturbance of the normal amount of torsion may be a source of discomfort, and this happens in some cases, at least, when an astigmatic glass is not set at the proper angle. That will be considered in detail in the part of our study which relates to pathology.

CHAPTER IX.

BALANCE OF THE OCULAR MUSCLES.

§ I. **Factors in the Production of Comfortable Vision at the Near Point.**—We have been devoting ourselves principally to the study of three functions of the ocular muscles, namely, accommodation, convergence, and torsion. Each one of these has been studied separately and also in its relation to the other two functions. But we must not lose sight of the equally important fact that each one of them is directly influenced by what may be called the "resistance" to the muscular effort made. It was because of the importance of this resistance offered, that several apparent digressions have already been made in the course of our study. Thus taking the act of accommodation we have concluded that the principal function of the intraocular muscles is to change the form of the lens and the size of the pupil so as to produce a clear focus on the retina. But the effort to accomplish that result may be made difficult or impossible by what may be called the "resistance" offered. This may be, as we know, an excessive effort which must be made either because the eye is too short, or because the lens has become somewhat hardened, or because the cornea or the lens, or both, have an irregular curvature, or even because the innervation of the ciliary muscle is insufficient. Any or all of these conditions may constitute what we may call resistance. For the sake of convenience, we may indicate this resistance to the accommodation by R_1.

In the same way convergence may be influenced more or less by the resistance offered to it. That may be because of the excessive development of any one or all of the abductor group of muscles, or imperfect development of any one of the adductor group, or the obstacle to be over-

come may depend on the shape of the globe, as in myopia, or spring from imperfect innervation of the adductors, or even be due indirectly to insufficient action of the ciliary muscle. Any or all of these conditions, or conditions similar to them, we may group together under the general term of resistance to the convergence, and indicate it by R_2.

It would appear that the same principles apply to torsion, as far as it is possible to make any statement concerning that third factor. When one group of muscles is called into action in rotating the upper end of the vertical axes outward, it is fair to say that the opponents of that group act as a resisting power in preventing an insufficient or an excessive torsion. Indeed, clinical evidence shows beyond doubt that the power of making sufficient torsion is influenced by pathological conditions. That obstacle or obstacles, whichever it may be considered, produces the resistance offered to the muscles which normally produce torsion, and this resistance we may indicate by R_3. Evidently, therefore, in considering comfortable vision for the near point, we have to do with the three primary factors, accommodation, convergence, and torsion, and in addition we must consider the resistance which is offered to each of them. That resistance may be a secondary factor, it is true, but nevertheless it must be taken into account. Practically, therefore, we have three pairs of factors, or at least six different elements, as it were, in the act which we call vision at a near point.

§ 2. **A Simple Method of Representing by Diagram the Amount of Accommodation, Convergence, or Torsion Which Exists in a Given Case Together with the Amount of Resistance Offered.**—This will be understood at once by recalling the well-known method of representing accommodation by a straight line. It is seen in A, Fig. 228. It is an old method (page 144) often employed by Landolt and others, and is simply a graphic representation of the amount of accommodation.

If ophthalmoscopic examination and other tests show the eye is emmetropic, and the resistance to the accommodation is normal—that is, in proportion throughout to the amount

of accommodation, — we can represent the resistance of the emmetrope on a similar horizontal line, which is also divided into equal parts, each representing one diopter. It is evident that the line which represents this would be of the same length and would extend through the same divisions as does the line which represents the range of accommodation. This is shown by the line R_1.

Just as the range of accommodation can be represented on a line divided into equal parts, so we can represent the range of convergence on a line divided into equal parts, of the same size as those which represent accommodation, each of which divisions corresponds to one meter angle. Thus, if the range extends from infinity to ten meter angles,

FIG. 228.—Diagrammatic illustration of muscle balance (Eukinesis). In this young person the accommodation, convergence, and torsion, with the resistance to each, is normal up to 10 D.

such a range would evidently occupy ten of the spaces referred to.

Also, the resistance offered to the convergence may be represented on a similar line divided into equal parts, each of which corresponds to one meter angle of convergence. This is seen in R_2. The method of estimating the amount of resistance which is offered to convergence will be elaborated later. At this point, it must suffice to say that it depends upon whether the individual under examination shows an orthophoria, an esophoria, or exophoria, and if either of the latter is present, then in what degree. Thus, with orthophoria we may assume that if the eyes are otherwise normal, then the power of convergence is in proportion to the amount of accommodation exerted. When exo-

phoria exists, and in a degree, for example, representing two meter angles, the adductors have that extra amount to overcome.

Esophoria may be shown in a similar manner. Finally, torsion and the resistance to it can each also be represented by divisions on a line. As we know from the tables of Landolt and from the other measurements of normal eyes about how many units of torsion in the horizontal plane, for example, correspond to a given amount of convergence, so it is possible to represent torsion on a line divided into equal parts, each one of which corresponds to one diopter of accommodation. (T, Fig. 228.)

The resistance which is offered to torsion with a given degree of convergence could also be represented on a similar line and in a similar manner. It is true that our knowledge of this latter subject is as yet far from complete, but such facts as we have warrant us at least in recording what we do know of torsion, just as we record both accommodation and convergence, and the resistance offered to each of them.

It would lead to too long a digression at this point to describe how it is possible to represent in this way abnormal accommodation, convergence, or torsion, and the resistance which is offered to each, but in the future it will be necessary to refer quite in detail to these graphic representations of muscle imbalance. The object in calling attention to this graphic method at this point is merely that we may obtain a clearer mental image of each of these six different factors and their relation to each other.

§ 3. **Muscle Balance.**—This term muscle balance has been used to express almost anything or nothing. It is too often confused with what Stevens called orthophoria (B 725) or with his *euphoria* (B 543, p. 227). In the very excellent nomenclature which he proposed and which we have generally adopted, the 'phorias, as repeatedly stated, refer to passive tendencies of the eyes to assume certain *positions*. They do not take into account in any way the action of the ciliary muscles. But when we speak of

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muscle balance we refer not simply to the extraocular but also to the intraocular muscles. In view of this, and of the foregoing, we may say that *muscle balance is the condition in which with comfortable binocular vision accommodation, convergence, and torsion bear their normal relations to each other.* Such a definition, although elastic, is better than none, for we evidently need a physiological standard with which to compare various forms of muscle imbalance, or unbalance, as it is sometimes called.

From this definition it is evident that the term muscle balance is relative and depends on numerous conditions. A few of these should be mentioned, for example:

(A) The age of the individual influences greatly what may be called the range of muscle balance. Thus in early youth, when the range of accommodation and convergence is large, there is a corresponding large range in which we can expect to find muscle balance.

(B) The employment of the individual affects muscle balance. Persons who use their eyes only occasionally for close work can maintain that effort for a longer time each day than do those who must tax the ocular muscles by constant near work.

(C) The so-called general health of the individual is a factor of no small importance in the maintenance of muscle balance.

(D) All such factors vary with the same individual at different times. Thus, a person may have perfect muscle balance when looking at a distant object, but not at 20 cm. or 25 cm. or even at 33 cm; or he may have muscle imbalance without glasses and muscle balance with them. Indeed, we shall learn that the principal object of glasses is to make the balance as perfect as possible when an imbalance exists. The English term muscle balance is evidently better than any other, though if we wish for a synonym of classic terminology we could use eukinesis (*eu*, well; and *kinesis*, strength).

The differences between orthophoria and muscle balance or eukinesis can be understood best by comparing one with the other, thus:

Orthophoria	Muscle Balance (Eukinesis).
1. Relates to extrinsic muscles only.	1. Relates to extrinsic and intrinsic muscles.
2. Visual lines tend to parallelism.	2. Visual lines parallel or converging.
3. Binocular vision may or may not exist.	3. Binocular vision must exist.
4. Comfort may or may not exist.	4. Comfort is essential.

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CHAPTER X.

RELATION OF THE "GENERAL STRENGTH" TO THE PHYSIOLOGICAL ACTIONS OF THE OCULAR MUSCLES.

We have now completed a review of the functions of the various muscles of the eye. But some mention should be made of the relation between the fusion power or "strength" of the ocular muscles and what may be termed the general strength of the individual. In dealing with this question it is desirable to express the relationship in figures as far as possible—that is, to obtain the power of adduction, abduction, etc., in terms of a prism, then to determine the condition of the muscles of the body as expressed in foot-pounds, and finally to compare these two with each other.

We have already learned how the strength of the eye muscles can be expressed approximately, at least, in terms of a prism. It is sufficient, therefore, at this point to observe that when we take into account *both* the minimum and maximum power of different groups of the ocular muscles—for example, adduction and abduction—each measured thus by different methods, we have at least an approximate expression of the strength of the ocular muscles in that individual.

Second, let us see what is meant by the term general muscular strength or strength of other muscles, and ascertain how that also can be expressed in figures. Formerly it was supposed that this might be estimated by the weight of a dumb-bell which could be lifted, or by the performance of some other special feat. But in these tests much depends on a single group of muscles or on some art of the performer. Several forms of dynamometers have also been constructed, some of which are excellent, but they show only the strength in the arms as the instrument is grasped

forcibly by the hands, or of the arms and legs, etc. Of late years rather more accurate measurements of the general muscular strength have been secured, by Dr. Sargent, Director of the Hemenway Gymnasium at Harvard. He evolved what he calls a "Universal Test for Strength, Speed, and Endurance" (B 825), which is simple, and is destined apparently to be of some value to ophthalmologists as well as to physicians, because this shows what the general muscular condition of an individual is at any given time, and because the exercises which serve as this "test of strength" constitute also an excellent method of improving the muscular tone.

It would necessitate too long a digression at this point to describe each of these tests of strength in detail. They will be discussed in the chapter in the second volume which deals with central asthenopia. For our present purpose it must suffice to say that these exercises consist simply in lifting certain parts of the body a certain number of times within a certain number of minutes. Thus, if an individual who weighs 150 pounds, and who is five feet high, lying on his back can lift himself to a sitting posture (approximately 75 pounds two and a half feet), and do this thirty times within ten minutes, evidently the strength expended can be stated as 5,625 foot-pounds. Various other exercises of a similar kind can be used which give us a standard for measuring the general strength of that individual. It has been found in general that the average healthy man can lift in this way in half an hour about forty-five to fifty thousand foot-pounds, although by systematic exercise the amount may be increased, as with athletes, to seventy or eighty thousand. The general strength of women is naturally less, and ranges from about twenty or thirty to forty thousand foot-pounds in half an hour. In children it is, of course, proportionately less.

The next question before us is whether any relation exists between the strength of the ocular muscles as expressed in terms of a prism, and the general strength of the individual as expressed thus in foot-pounds. To obtain some idea of this, an examination was made by Dr. Charles H.

Williams of Boston and myself, at the Harvard Gymnasium, of the normal eyes of twenty-nine students whose general strength had been carefully measured. Also, in a considerable number of cases of heterophoria in which for various reasons systematic muscle exercise was practised, the general strength has also been recorded.

The conclusions from these observations, briefly stated, are:

First: Suitable tests show that under normal conditions the minimum power of adduction and abduction remains at about the normal amount, no matter what may be the general strength of the individual.

Second: The maximum power of adduction is to a certain extent in proportion to the general strength of the individual.

Third: In cases of heterophoria, when so-called muscle exercise is practised when the general strength of the individual is quite up to the normal standard, the maximum power of adduction or abduction can be increased more rapidly, on the average, than in other individuals whose general strength is apparently less than normal.

In any such discussion it would be an omission not to take into account what may be called the "muscle tone." This condition, long recognized by physiologists as the *tonus muscularis*, does not refer to the strength or lifting power. It is not easily defined, though well recognized as the ability of a muscle or group of muscles to perform the amount of work normally devolving upon them without the development of fatigue in those muscles or in other parts of the body. Unfortunately we have no exact methods of measuring this tone except by the feelings of the individual, and these, of course, are much influenced by the personal equation. There can be no question, though, but that this normal tone of the ocular muscles is also in proportion to the tone of the muscles in the other parts of the body of that individual. Thus, as a rule, we find that where the muscle tone of the individual is low—that is, where the other muscles are easily fatigued or utterly unable to do their work, there is usually a difficulty of the ocular muscles also

in performing the work which is imposed upon them. On the other hand, when the general muscle tone is high, as we find in a strong and well developed individual, the tone of the ocular muscles bears a certain relation to that. It is true that we often find invalids who can read and write all day under adverse circumstances without inconvenience, but these are rather exceptions to the general rule.

The practical importance of this relation between the strength or the tone of the ocular muscles and the strength or tone of the muscles of the body as a whole is apparent at once. It means, in a word, that where we find an imbalance or fault of the muscles, we should not be satisfied in attempting to correct this by optical appliances or other local means, but whenever the general strength of the individual is at all below the normal standard, as measured by exact tests, the strength or tone of the other muscles of the body should also be improved.

CHAPTER XI.

RECAPITULATION AND CONCLUSIONS.

§ 1. **Recapitulation.**—When concluding one of his courses of lectures, Tyndall compares the progress made by the student to the gradual ascent of a mountain, and reviews the course pursued in order to obtain a general view of the entire subject. So can we also now recapitulate with advantage the salient points observed, and estimate what real progress, if any, has been made, and what conclusions we have reached in this study of the muscles of the eye.

We began in the most elementary manner with dissection of the extraocular muscles; we observed the difference between their primary and secondary insertions, particular attention being given to the latter, which, though so often disregarded, are none the less of extreme importance in their relation to operations for tenotomy and advancement.

We examined next the intraocular muscles, or rather the different structures concerned in accommodation. This meant not simply the ciliary muscle, and the manner in which it was connected with the lens, but the position and structure of the lens itself. In doing this we made a modification of the Javal ophthalmometer to show the position of the lens. For, as the object of the ciliary muscle is to change the form of the lens so as to produce a perfect focus, imperfections in the position or structure of the lens, or imperfections in other medias, present what might be considered a resistance to the action of that muscle. These different imperfections, as they occur in the practically normal eye, were therefore examined with some detail. Moreover, in passing, we noted also the relation which the muscles of the forehead, especially the two parts of the occipito-frontalis, bear to the act of accommodation; for, as we shall see later, the

contraction of these muscles in abnormal accommodation is at least one of the sources of "ocular headaches."

In the study of the nerve supply of the muscles we again began with the most elementary facts, and, adding to these the latest discoveries of the best observers, tried to obtain a clear picture of the various nuclei, their structure, and the distribution of the different fibers. This part was necessarily a digest of the work of well-known histologists and physiologists.

Comparative anatomy and embryology were examined only briefly, in spite of the temptation to dwell upon them because of their general scientific interest.

Passing next to the physiology of the muscles, we considered first one eye at rest, in order that we might review those fundamental principles relating to it, as a globe rotated in different directions by the different muscles. In this connection we found that by modifying the ordinary Javal-Schiotz ophthalmometer it was possible to determine with that, quite exactly, the center of motion.

A special chapter was also devoted to the globe in action, but not necessarily in motion, as when the internal muscles contract in accommodation. For as that act must be constantly referred to, especially when studying the pathology of the muscles, it seemed essential to understand just what is meant by it. In that connection we glanced at the well-known action of full doses of cycloplegics and of mydriatics, and, what was quite as important, we observed the effect of what we called "minimum doses" of several of these drugs upon the normal eye. This gave us a physiological standard, which, within certain limits at least, serves as a measure by which to determine, in any given case, whether the ciliary muscle relaxes or contracts more promptly than natural. In other words, this helps us to determine whether there exists a tendency to excessive or to insufficient accommodation.

In considering the manner in which the extraocular muscles move the globe, it seemed best to confine our attention first to the motion of one eye only. In this way we could study a large part of the ocular motions, eliminating all forms of associated movements. For that purpose we

constructed a new ophthalmotrope. We observed what the action is of a single muscle. We noted for the first time the lifting power of the adductors and the tensile strength of the recti. We simplified the apparatus to measure the rapidity of the lateral movements of the eyes by means of photography. We found what that motion is in the natural condition, thus obtaining a standard by which to determine in doubtful cases whether there is an imperfection of the movement to one side or the other. Also, we examined at considerable length the limits of the field of fixation; we studied the claims of the tropometer and of the perimeter to exactness in measurements of this kind, and found that various improvements could be made, especially in the latter instrument.

As one eye was studied first at rest and then in motion, so the two eyes acting together were considered first at rest and then in motion. We found it was by no means easy to ascertain just what position the eyes assume when in a position of "rest," and the different tests of the static position were therefore divided into groups in order to distinguish them more readily from each other. Thus, we had first a group of tests which produced a *displacement* of one or both retinal images, a second group including those which produced a *blurring* of one of the retinal images, while the third group included those in which one eye was *covered* or excluded from the act of binocular vision. We compared these different groups of tests with each other, to ascertain as nearly as possible their relative values. We found that orthophoria was by no means always present in the normal eyes, but that the majority of practically perfect non-asthenopic eyes tend to turn sometimes in one direction, sometimes in another, in order to assume their position of rest.

After understanding the position which the eyes tend to assume when "at rest," we were better prepared to examine the motions which the two eyes make in an effort at binocular vision. These associated movements were found to separate themselves also into certain groups.

Thus, in the first group of motions, the visual axis being

in the primary position, the vertical axes turn in or out. This led us to glance at various earlier methods of measuring the true torsion or wheel motion which is possible with parallel visual axes. We examined the Volkmann discs, the application of them to the Stevens clinoscope, and then applied them to a new form of the clinoscope apparently simpler and with a wider range of usefulness.

A second group of motions we found to include those in which the parallel visual axes move in some one of the principal meridians, up, down, in, and out. By the use of after-images we found that in these motions no true torsion occurred.

The third group of associated movements we learned included those in which the visual axes moved obliquely from the primary position into some secondary position. In doing this again no true torsion occurred, but there did occur a certain apparent turning of the vertical axes about the visual axes in such a way as to give to the observer of the after-images the effect of torsion. This led us to the calculation of the degree of false torsion by a new formula.

The fourth group of associated movements we found to be the most important in its clinical aspects; so important, indeed, that in order to study it properly it was considered in five divisions. As a preliminary step, we reviewed the well-known facts relating to ophthalmological prisms—we glanced at the meaning of the meter angle, expressed the size of meter angles in degrees with exactness, and constructed a table of degrees in terms of the meter angle. We also established the difference between the minimum and maximum fusion power — a point of no small clinical importance.

Thus we were better prepared to study the variations in accommodation with a given degree of convergence—that is, relative accommodation. We saw how it could be illustrated graphically; we ascertained how the measurement of relative accommodation was made, and the results plotted, and observed how relative accommodation is influenced by increasing age,—this last fact being of decided clinical value in determining whether or not the ciliary muscles have a normal,

a subnormal, or an excessive power of contraction. After studying relative accommodation we passed to relative convergence, saw what that was, what the desiderata were for its measurements, and also what degree of exactness was necessary for clinical purposes.

Finally we examined the true torsion which accompanies convergence, and saw what this is in the horizontal plane and in other planes inclined below or above the horizontal.

Also what we may call relative torsion was treated as we had already treated relative accommodation and relative convergence. We saw, however, that these complete measurements are required for clinical purposes only in rather unusual cases, and that ordinarily a very simple procedure is sufficient to indicate, at least, whether the amount of relative accommodation, or convergence, or torsion possessed by a given individual can be considered normal or abnormal.

The facts ascertained up to that point led us to the conclusion that in the act of comfortable vision for the near point we have to deal with three principal factors—namely, accommodation, convergence, and torsion; or, if we take into account what may be called the resistance to each of these, that we have then three secondary factors, or six altogether. In considering these different factors we found that as long as they all acted together, within normal limits, there existed a condition which might be called ***muscle balance***.

§ 2. **Conclusions.**—After this study of the anatomy and physiology of the ocular muscles, and after a recapitulation of the points to which attention has been specially called, still the practitioner may ask himself—What of it? How do these tests and methods of examination lessen our confusion of ideas concerning the ocular muscles, or assist us in the routine of daily work? This is a natural question, and even such a partial answer as can be given while our study of the subject is only half finished may be better than none at all. In a general way, therefore, it would seem that thus far we are led to certain conclusions:

The first one is that a thorough study of the anatomy

and physiology of the muscles is essential to a working knowledge of their pathology. At first glance it seems a waste of words to state such an axiomatic truth as a conclusion. But when we consider the complexity of the questions involved in this subject, how they have to do with mechanics and optics—both involving the higher mathematics,—also, how a study of the fusion of images leads us into the borderland between physiology and psychology,—when these and other details are considered, we may even say that the completeness of our clinical work with the muscles is about in proportion to our knowledge of their anatomy and physiology. It is true that some of the facts stated in the foregoing pages are given rather for completeness, and many others can be found in the literature which are unnecessary refinements made by laboratory students and have no bearing on clinical work. But it is also quite true that the knowledge which the average ophthalmologist has of the anatomy and physiology of the muscles of the eye is not sufficient for the best clinical work.

Second, more exact definitions are necessary of much of the anatomy and physiology of the ocular muscles if we would clear up in any way our confusion of ideas concerning them. For example, from the anatomical standpoint, and, therefore, for surgical purposes, we must distinguish the primary from the secondary insertions. Or physiologically we must distinguish the passive states (the 'phorias) from the active conditions (the 'ductions). Among the latter we must also distinguish the minimum from the maximum power of adduction, abduction, etc. By keeping these and many other such differences in mind our ideas of the subject become proportionately clarified.

Third, we need greater uniformity in methods of examination. No matter whether a test is made of the static or dynamic condition, or whether measurements are made of the power of accommodation or of convergence or of torsion, or of any one of these with reference to the other, we should agree on certain procedures to be adopted; or, if that cannot be done, then each ophthalmologist should

describe his methods in his own records for his own convenience, or surely when writing for others. The results which we obtain depend to so great a degree upon the details of examination, that uniformity is a necessity if we would understand each other, or if the same observer wishes to interpret intelligently observations made by himself at different times.

Fourth, as a corollary from the foregoing, we may conclude that the practitioner must make his clinical examinations much more thorough than is usual, if he wishes to obtain a sufficient number of data upon which to base a final opinion.

With most ophthalmologists the routine of examination is about as follows: To obtain the clinical history, measure the refraction first objectively, then subjectively, the range of accommodation, the relative accommodation at the far point, and perhaps at the near point. As for the extrinsic muscles, the static condition with parallel axes is tested, and perhaps at three meter angles of convergence. Also the dynamic condition for distance is measured, and occasionally at the near point. In cases where the surgeon happens to judge that a cycloplegic is indicated, he drops some homatropin or atropin in the eye, not knowing how much is used, nor caring for any effect except to place the accommodation at rest, if indeed that is done.

Such an outline, or one which is much more schematic and scanty, furnishes all the data which it is usually deemed necessary to have. Many practitioners are satisfied with a much less thorough examination than this, certainly at the first consultation, and some do not make it more complete no matter how often an opportunity for re-examination is presented.

Although this outline, or one similar to it, is sufficient in a certain way, and although it is often more than is possible for a busy practitioner in his daily work, yet any reader of these pages must admit to himself, if not to others, that a diagnosis based upon such data must necessarily be *only a provisional one.*

The truth is that a certain number of cases do return to us with the same symptoms in spite of all the care that

can be given at an ordinary first visit. In fact, they return not only once, but a second or third time, or perhaps many times, still with the same complaints; or else, being discouraged and dissatisfied with one practitioner, they float about from office to office, each time passing through the same routine of superficial examination.

Now one of the main objects of this entire study is to show that the practitioner may still learn a great deal more concerning these unsatisfactory cases, if he makes his examinations according to the methods which have here been even imperfectly outlined.

In order to see more specifically what this means, let us suppose, first, that we have to do with a case in which the person complains of the cardinal symptoms of what we usually call asthenopia. If the glasses prescribed do not give sufficient relief, the practitioner naturally asks himself again whether the fault is due especially to the intraocular or to the extraocular muscles. As the former condition is much the more common, he naturally reviews his data, asking himself whether the patient has an *actual insufficient* power of accommodation (a paresis), or whether the insufficiency is only *relative*—that is, due to an existing hypermetropia or to a hypermetropic astigmatism; or, on the other hand, whether there is present an *actual excessive* power of accommodation (spasm), or a *relative excessive* accommodation such as exists when the ciliary muscle is in a practically normal condition in a myopic eye.

In order to answer these questions, which relate only to the condition of the intraocular muscles, it becomes necessary, if the symptoms warrant it, to apply a minimum dose of atropin sulphate, and by measuring its effect every five or ten minutes to obtain at least some idea of the condition of the ciliary muscle. Or if the patient returns again, and if it is still suspected that the symptoms are due to some anomaly of the accommodation, it may then appear desirable to measure quite exactly the range of relative accommodation. Until all these measurements have been made, and still others here described, no surgeon can honestly con-

clude that in a given case he has collected all of the data which relate simply to the intraocular muscles.

But another factor in our problem is the condition of the extraocular muscles. In the large majority of cases, of course, no instruments or other apparatus are necessary for these except the prisms of the trial case, or such modifications of them as are in the hands of most practitioners. But in certain cases such prisms are insufficient, especially for the measurement of relative convergence. And even after determining that and other facts of the same class, the examination of the extraocular muscles is not completed until we know the amount of torsion exercised, whether this is in the horizontal plane or in some other which is inclined to the horizontal, and what this amount of torsion is with varying degrees of convergence.

But after every possible effort has been made to determine the refraction of the eye, the condition of the intraocular muscles and of the extraocular muscles—in other words, after we have learned all we can concerning the eyes themselves, and after the most careful and intelligent efforts have been made to remove the cause of the difficulty, the patient may still return with some or all of his original asthenopic symptoms. Even then the honest practitioner must admit to himself that he has not learned all that is possible in regard to the case. He remembers that the principal factors which enter into the act of comfortable binocular vision may be influenced by what is called in general "impaired nutrition." Accordingly he makes tests, or has them made, to determine the condition of the stomach, of the kidneys, of the blood, or otherwise to assure himself that the functions of the body are as near to normal as possible.

All of the foregoing tests may be advisable or necessary simply in a case of what we call "asthenopia." But again let us suppose that we have before us a case of what we call in general terms a paralysis of one or more of the extraocular muscles. At the first visit, the simpler test of double vision must ordinarily suffice. If, however, we wish data which are reliable for an exact diagnosis, it is desirable to measure the field of fixation with the perimeter or otherwise much more

exactly than is ordinarily done, in exceptional cases to measure possibly the rapidity of the lateral movements, or employ other means to assist in deciding what parts of the brain, if any, are involved.

Finally, let us suppose that we have before us still a third case, such as is usually called one of convergent strabismus. Whatever other questions may arise as to the causation or pathology in that individual case, if any form of operative treatment is to be considered, the first question to be asked is, as we shall see later, Does the eye turn in because of excessive action of one or both interni, or because of relaxation of one or both externi? On the answer to this question depends the decision whether we are to make some form of tenotomy of one muscle, or advancement of another muscle. In order to answer that question it is necessary, as has been so often urged, to employ methods of examination which are too often neglected, but which have been described in detail in the foregoing pages. But if operation is decided upon, we find that the anatomical studies which we have made give us valuable suggestions as to method and technique. They show us how important it is to distinguish between the primary and secondary insertions. We see the importance of the division of the secondary insertions alone, or of the primary insertions alone, or of both of these together; or, on the other hand, of the tucking operation, or of advancement in its different forms.

In our studies thus far we have halted frequently to take bearings and note the relation of the subject under consideration to the demands of clinical work. Now again, after reviewing the whole theme, we have observed its relation to the examination of three of the most common types of cases with which we have to deal. It is hoped that these examples indicate at least in some degree how it is possible to make our measurements of the ocular movements much more thorough and complete than is ordinarily done. If that has been made clear, we have prepared a foundation of anatomical and physiological data for our clinical work, and the main object of this first part of our study has been accomplished.

APPENDIX A.

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APPENDIX B.

SUBJECTS FOR STUDY.

Reasons for this List of Questions.—As a traveler finds numerous paths leading from the main road which he is pursuing, so in this study questions connected with the main topic have often arisen. At first they were noted with the expectation of returning to them. But it soon became evident that one life was far too short for working out all the unsolved problems relating to the ocular muscles. A few of these questions are therefore added in the hope that they may prove suggestive to future students. For it is unfortunately evident that much energy and professional zeal run to waste for lack of intelligent guidance. Our ranks are recruited each year by ambitious men, well equipped for their work, and with ample time for investigation, especially in their early years of practice. As the entire field is fresh to them, they turn to whatever part is of special interest, too often making the great mistake of not ascertaining first what has been accomplished by other workers. The result is a loss to our science of valuable energy and patient labor and a disappointment to the student, when he is shown later that his "new truths" were discovered years before. As the same mistake is often made also by those of us who are old enough to know better, we find our literature full of repetitions. This is particularly so in America, and pre-eminently, it would seem, in articles relating to phases of so-called eye-strain. Therefore it may be a convenience for those who possess the desire and opportunity to study this subject further, to have suggestions as to at least a very few of the problems which yet remain to be solved. As in certain branches of manufacture the by-products become ultimately more important than the substance which first was made, so in this list of subjects for study it is hoped that the results obtained may prove much more valuable than the work which has called attention to them.

QUESTIONS.

Can Kaiserling's method for preserving specimens be improved—especially in preventing the specimen from becoming hard?

What stain of connective tissue can be found which is more selective than those we now have, and in colors which show better in photographs?

Measure a considerable number of globes according to the method here outlined to ascertain the average position, length, and curve of the primary insertions of the recti.

In three or four orbits inflate the globe, make moderate traction of the internal rectus, or extreme traction, harden the specimens with the globes in these different degrees of adduction, make horizontal sections, and observe the exact condition of the check ligaments.

Make a series of horizontal sections showing the details of Horner's muscle.

Show the action of Horner's muscle and its exact effect on the sinking of the caruncle after tenotomy of the internal rectus.

Of what practical importance, if any, is the sound produced by the eye muscles?

What is the exact location of cells in the cortex of the brain which give rise to nerve fibers supplying the muscles?

Do the experiments of Ferrier show conclusively the existence of motor centers in the cortex?

What bands of fibers are there which pass from the cortex or other portions of the brain to the nucleus of the motor oculi?

What further evidence can we obtain by the degeneration experiments of Von Gudden to ascertain which cells in the nucleus of the motor oculi preside over certain muscles?

Demonstrate the anastomoses between the third and other nerves.

When operating on different members of the same family who have squinting eyes, measure accurately the position, length, and form of the arc of the primary insertion of the muscle which is divided.

How many conjugate innervations are there and what *proof* of each?

With the aid of the ophthalmophacometer, measure the size of the angle alpha and the tipping of the lens in a considerable number. A. Of normal eyes. B. Of eyes in asthenopic persons.

What is the relation of astigmatism to the size of the angle alpha?

What are the points of origin and insertion of the fibers constituting the Zone of Zinn as they pass from certain parts of the ciliary process to the anterior and posterior portions of the lens?

Does the Zone of Zinn vary greatly in different individuals?

Repeat the observations of Crzellitzer and Stadfelt to see whether the anterior surface of the lens becomes more convex during accommodation.

Repeat the experiments of Volcker and Hansen to ascertain the changes: A. In the choroid. B. In the posterior surface of the lens, if any occur during the act of accommodation.

With the aid of Tscherning's ophthalmophacometer, observe the changes in the entoptic images during the act of accommodation and give an explanation of them.

Repeat the experiments of Heine to verify his statement concerning the falling of the lens during the act of accommodation.

With the aid of the ophthalmophacometer observe the apparent astigmatic accommodation which occurs in: A. Normal eyes. B. In eyes of asthenopic persons.

Measure the form and the degree of malposition of the lens in different members of the same family who suffer from obstinate forms of eye strain.

Observe more accurately the characteristic contraction of the pupil in different individuals.

Repeat the experiments of applying atropin and eserin to the eyes of animals, removing the eyes, freezing them immediately, and making sections to determine the form of the lens and condition of the ciliary muscles.

What difference is there in the action of a given amount of any cycloplegic or myotic upon the ciliary processes of individuals of different ages?

What curve do we obtain for the relaxation of the accommodation and dilation of the pupil after the use of very weak solutions of duboisia, scopolamin, and of similar drugs?

Exactly what connection is there physiologically between the posterior fibers of the occipito-frontalis and the trapezius which may account for the pain which extends from the occiput over the shoulders when prolonged efforts at accommodation are made?

In any considerable number of cases what is the lifting power of the adductors?

What better method can be proposed for measuring the lifting power of the adductors?

What is the usual lifting power of the adductors in youth? In middle life? In old age?

Does the lifting power of adductors vary in proportion to the muscular development of the individual?

What is the amount of muscular force expressed in grams which is necessary to rotate an eye outward: A. In esophoria of a certain degree? B. In exophoria of a certain degree?

Is the relation of torsion to accommodation the same as the relation of torsion to convergence?

What better explanation can we give of the mechanism of associated lateral movements than the one which we now have?

Of what clinical importance is the difference between the binocular and monocular near point?

What simpler methods can be found for the measurement of relative accommodation?

In a considerable number of emmetropes what line or curve represents their average range of relative convergence?

What are the causes of the apparent variation of relative convergence among different emmetropes?

When measurements are made of a considerable number of emmetropic eyes as to the degree of torsion with convergence in the horizontal plane and in oblique planes, do the figures thus obtained accord with those given by Landolt?

What better methods can be found for the measurement of relative torsion?

In a considerable number of emmetropes exactly what relation exists between the strength of the recti, as expressed in prisms, and the strength of the individual as expressed in foot pounds?

APPENDIX C.

OPHTHALMOLOGICAL JOURNALS IN CERTAIN AMERICAN LIBRARIES.

The student who cares to pursue this subject further, may perhaps see articles in the bibliography which he thinks would particularly interest him. It is true that volumes can often be obtained from the Library of the Surgeon General at Washington, either directly or through local incorporated libraries, and the opportunity thus afforded to the humblest student is a source of congratulation to the medical profession of the country. There are, however, numerous inconveniences in obtaining books from this source. It involves, of course, delay and expense of transportation, and the volumes can be kept but a short time, as the purpose of that library is avowedly not to send books out, but to keep them for consultation in Washington.

It has therefore seemed desirable to ascertain where files of the ophthalmological journals are to be found, and although this list of periodicals is not quite complete, it is probably sufficient for the needs of most students. The numbers in the first column on each page indicate the name of the periodical as that is given in the list. As the last column on the page following this one shows the year when each periodical first appeared, it is possible, by counting from that date, to determine the number of any volume; or if the number of the volume is given, the year can be determined. This list may prove convenient not only to the student of the muscles of the eye, but for other departments of ophthalmology.

LIST OF PERIODICALS.	First Vol. Published in
1. American Journal of Ophthalmology	1884
2. Anales de Oftalmologia (Mexico)	1900
3. Annales d'Oculistique	1838*
4. Annali di Ottalmologia	1871
5. Annals of Ophthalmology	1892
6. Archives d'Ophtalmologie	1880
7. Archives of Ophthalmology	1869
8. Archivio di Ottal. (Palermo)	1893
9. Beiträge zur Augenheilkunde	1895
10. Bericht der Ophthal. Gesellschaft, Heidelberg	1877
11. Bolletino d'Oculistica (Firenze)	1870
12. Bulletin Société Française d'Ophtalmologie	1883
13. Centralblatt für praktische Augenheilkunde	1897
14. Clinica Oculistica	1900
15. Clinique Ophtalmologique	1895
16. Graefe's Archiv für Ophthalmologie	1854
17. Klinische Monatsblätter für Augenheilkunde	1863
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19. Nederl. Tijdsch. v. Geneeskunde	1857
20. Ophthalmic Record	1891
21. Ophthalmic Review	1881
22. Ophthalmic Year Book	1904
23. Ophthalmologische Klinik	1897
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25. Ophthalmoscope, The	1894
26. Proceedings Western Ophthal. and Otolog. Association	1897
27. Recueil d'Ophtalmologie	1873
28. Reports Royal Lond. Ophthal. Hospital	1857
29. Revue Général d'Ophtalmologie	1882
30. Trans. Internat. Ophthal. Congress	1857
31. Trans. of the American Ophthalmological Society	1865
32. Trans. Ophthal. Society of the United Kingdom	1880
33. Trans. Section Ophthal. American Medical Assoc.	1891
34. Wochenschr. f. Ther. u. Hyg. des Auges	1897
35. Zeitschrift für Augenheilkunde	1899

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20	V. 1	To date	Yes	V. 1	To date	Yes	V. 1	V. 14	Yes
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22	....	....		V. 1	To date	Yes	......	....	
23	....	....		V. 1	To date	Yes	V. 5	V. 9	Yes
24	V. 1	V. 7	No	V. 1	To date	Yes	V. 1	To date	Yes
25	....	....		V. 1	To date	Yes	V. 1	V. 3	Yes
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INDEX OF AUTHORS.

INDEX OF SUBJECTS.

BIOGRAPHIC NOTES

OF A FEW EMINENT STUDENTS OF THE OCULAR MUSCLES.

The beginner in any branch of science too often forgets that he is the "heir of all the ages," and that any text-book is largely a digest of the work of many former laborers in the same field. But after one has confined his studies for some time to a subject which is apparently small, and, in doing so, found frequent evidences of the patient investigation of others, such a student often desires some glimpse of the personality of the men who have already worked out many of his problems, and to whom he owes a debt of gratitude. These short biographic notes are therefore added with the pictures of a few men who have contributed especially to our knowledge of the anatomy and physiology of the ocular muscles.

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BREWSTER, SIR DAVID. Born December 11, 1781. Educated at the University of Edinburgh. Was ordained a clergyman, but gave up the ministry and devoted his life to the study of optics. Described the stereoscope in 1849. Between 1806 and 1868 published over three hundred contributions to scientific subjects relating principally to optics. Died February 10, 1868.

Helmholtz, Hermann Ludwig Ferdinand v. One of the founders of modern ophthalmology. Born August, 1821. 1849, Professor of Physiology and General Pathology, Königsberg; 1858, Professor of Physiology, Heidelberg; 1871, Professor of Physics, Berlin. Invented the ophthalmoscope and made other invaluable contributions to ophthalmology. His principal additions to our knowledge of the muscles are in the *Handbook of Physiological Optics* (1856) and in his frequent articles, especially in *Graefe's Archives*. Died September 8, 1894.

DONDERS, FRANS CORNELIS. Born May 27, 1818. 1848, Professor of Physiology, Utrecht; 1855, one of the editors of *Graefe's Archives*. In these archives there appeared frequent articles on accommodation, muscular movements, torsion, etc. In 1863 he published *Pathology of Strabismus*, and in 1864 his epoch making work on the *Anomalies of Refraction and Accommodation*. He made valuable contributions to our knowledge of the action of mydriatics and myotics and furnished many other data concerning the ocular muscles. Died March 24, 1889.

HERING, EWALD. Born 1834. Followed Purkinje at the University of Prag in 1870, as Professor of Physiology and Medical Physics. In 1895 occupied the corresponding chair at Leipzig. Voluminous writer in Poggendorff's *Annals* and in *Graefe's Archives*. Studied particularly binocular vision and the associated movements of the eye.

NAGEL, ALBRECHT. Born in 1833 in Danzig. Educated at Königsberg. Was a student of Albrecht von Graefe. Became Professor of Ophthalmology at Tübingen in 1874 and died there in 1895. His contributions to this subject were in showing the relation between accommodation and convergence as expressed by the meter angle. He also established the invaluable *Jahres-Bericht*, still published under his name.

LE CONTE, JOSEPH. Born in 1823 in Liberty Co., Georgia. 1845, College of Physicians and Surgeons, N. Y. Served in Confederate Army later. Professor of Natural History, University of California. Died 1901. Published careful studies of monocular and binocular vision, and investigations of torsion with convergence.

HESS, CARL. Born March 7th, 1863. Graduated in Leipzig, 1886. 1896 Professor of Ophthalmology in Marburg. Made investigations in physiological optics, especially of the act of accommodation. Frequent articles in *Graefe's Archives*. Recipient of the Graefe prize in 1900 particularly for his articles on accommodation. At present Professor of Ophthalmology at Würzburg.

TSCHERNING, MARIUS HANS ERIK. Born, 1854, on the Island of Fionie, Denmark. 1884, adjunct director with Javal of the laboratory of ophthalmology at the Sorbonne. Has made extensive researches concerning the mechanism of accommodation and in other departments of physiological optics. Author of work on that subject (English translation). Contributed articles on dioptrics and on the ocular movements to the third volume of the French *Encyclopedia of Ophthalmology*.

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